Mouse, Touch, or Fich: Comparing Traditional Input Modalities to a Novel Pre-Touch Technique

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ABSTRACT

Finger touch and mouse-based interaction are today's predominant modalities to interact with screen-based user interfaces. Related work suggests that new techniques interweaving pre-touch sensing and touch are useful future alternatives. In this paper, we introduce *Fich*, a novel pre-touch technique that augments conventional touch interfaces with tooltips and further "fingerover" effects, opening up the space in front of the screen for user interaction. To study *Fich* in-depth, we developed a *Fich*-enabled weather application and compared user experience and interface discovery ("serendipity") of *Fich* against the traditional input modalities *Mouse* and finger *Touch* in a user study with 42 subjects. We report on the results, implying *Fich*'s user experience to be rated significantly higher in terms of hedonic quality and significantly lower in terms of pragmatic quality, as compared to traditional input modalities.

CCS CONCEPTS

• **Human-centered computing → Interaction techniques**.

KEYWORDS

pre-touch, tooltips, input techniques, user experience, user study

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1 INTRODUCTION

Mouseover and hover effects are well-known in desktop settings where the user interacts with a personal computer using a computer mouse. These effects often serve the purpose of providing help and foster a feeling of control by displaying additional information. Users can learn more about the functionality of interface elements, such as an icon's meaning or a button's function.

However, an increasing number of today's personal computers are equipped with touch screens. These touch interfaces usually lack a similar technique to mouseover, which would allow especially novice users of a graphical user interface to safely explore the application without having to be cautious of performing errors (e.g., pressing the wrong links or buttons) and recovering from these.

Constraints of graphical touch interfaces are well known. Fellow researchers have, for example, proposed combining touch with pre-touch sensing (e.g., [2, 9, 12]) in order to address them. While techniques combining touch and mid-air interaction have already been proposed in previous research, there is a gap in studying the effects of such techniques in typical everyday applications with multiple pre-touch enabled interactive elements, and in comparing these novel techniques to state of the art interaction modalities. To close this gap, we developed a new interaction technique that we call *Fich* (derived from *Finger + Touch*). *Fich* brings tooltips and "fingerover" effects to touchscreens, potentially enriching touch screen interaction for a broad range of applications and websites. We claim that *Fich* will result in interface discovery support and general improvement of user experience compared to alternative techniques based on mouse and finger touch (without pre-touch sensing).

In order to study how *Fich*-based interaction is experienced in comparison to touch- and mouse-based interaction, we carefully designed and developed a custom weather application for a Microsoft Surface device and conducted an extensive user study with 42 participants. Study results demonstrate, for example, that *Fich*'s hedonic qualities are rated significantly higher and *Fich*'s pragmatic qualities significantly lower in comparison to the touch and mouse alternative.

In this paper, we summarize related work on interweaving touch and mid-air interaction, describe the novel interaction technique *Fich*, outline the user study conducted, and discuss the results in detail.

2 RELATED WORK IN PRE-TOUCH INTERACTION

Previous work argues that combining mid-air sensing and touch screens expands the interaction space. This helps to address usability issues such as

- acquisition of touch targets in cumbersome interaction contexts, as seen in driving cars [6]
- multiple users sharing the same small-sized touch screen [7]

- using interfaces designed for mouse and keyboard on touch screens [22]
- hand occlusion and the fat finger problem [20] when operating small-size screens (e.g., [9, 12, 14])

Moreover, researchers have highlighted that expanding the interaction space allows for the design of richer interactions by offering alternative input techniques and new functions. Ultimately, the resulting multimodal interaction techniques improve reactivity and responsiveness as well as increase user experience for many one-handed and two-handed interaction settings with mobile devices (e.g., [2–4, 12, 13]).

Early related research also exists in the field of tabletop interaction (e.g., [11, 21]). Marquardt et al. [18] and Annett et al. [1] have explored combining touch on tabletops and mid-air gestures above tabletop screens to create continuous interaction spaces and utilizing user proximity for interaction design. We have demonstrated in our previous research how tooltips on touch screen interfaces triggered by gaze improve user experience [5], motivating the study at hand, which focuses on finger-based pre-touch and thus complements results in gaze-based interaction research.

In addition to efforts in research, companies such as Samsung have started to include in-air interaction features such as "air commands" enabled by accelerometers in digital pens in their mobiles (e.g., the "Galaxy Note" product line). Consequently, empirical studies are needed to explore how users experience interacting with applications that combine mid-air and touch input in an advanced manner. In the following section, we describe in detail the prototype system, including the novel interaction technique and its graphical design.

3 FICH

We chose to design and implement a weather application, as checking the weather report is an everyday activity that does not require specific expertise. We named our weather application *Here Comes the Sun*. It provides a playful space in which participants are able to explore the different interaction modalities we are comparing. The following sections describe the application's design and implementation.

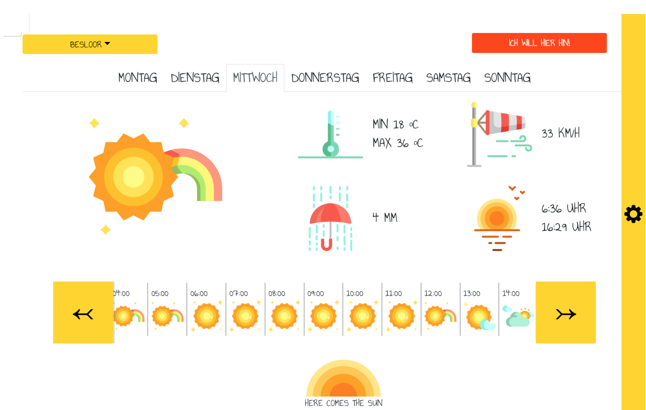

Figure 1: Main screen of *Here Comes the Sun*.

3.1 Design

Here Comes the Sun presents the user with a selection of three fictional cities, each populated with one week of generated weather data. The app's main screen is depicted in Figure 1. A drop-down menu on the top left allows switching between cities, a tab-based navigation at the top lets the user select a specific day of the week. For each weekday, general weather information on temperature, precipitation, wind, sunrise, and sunset is displayed. A carousel at the bottom provides additional details on each hour of the day.

On the right side, users can personalize the displayed units for temperature, wind speed, and time in a collapsible settings menu. We augmented various elements with tooltips that contain additional information: previews for currently unselected days, textual descriptions of the daily weather, and hours of sunshine. One tooltip also provides acoustic feedback — hovering over the sun near the bottom plays the song "Here comes the sun" from *The Beatles*. The app can be used in three interaction modalities: *Mouse*, *Touch*, or *Fich*. Depending on the mode of interaction, UI elements in *Here Comes the Sun* behave differently.

3.1.1 *Mouse.*

Most UI elements can be triggered by a left-click, e.g. selecting a city or a weekday, opening the menu, and scrolling the carousel. Tooltips appear when the user hovers over an element for at least one second. We do not process right-click or scroll as user input. The mouse cursor is visible at all times. It changes to a pointer whenever an element can be clicked or to a question mark if a hovered element shows additional information.

3.1.2 *Touch.*

Interacting by touch works similar to interacting by mouse. The user can select items by touching the display instead of using a left-click. Since there is no equivalent of a mouse hover for touch screens, tooltips are displayed whenever the user long-presses a certain element for at least one second. There is no cursor shown or similar feedback given at the position where the user touches the display. Deviating from the *Mouse* modality, the carousel can not only be scrolled by touching its surrounding buttons, but also by swiping the carousel's content to the left or right.

3.1.3 *Fich.*

In the *Fich* modality, we make use of the space in front of the display as user input in addition to conventional touch input. A cursor is rendered on-screen at the position the user points at with her index finger. When the user moves her finger in front of the display, the cursor follows instantly. Selecting a city or a weekday still works by touching the screen.

However, unlike the other two modalities, the size of the drop-down menu and tabs changes depending on the finger's distance from the screen. The closer the user's finger is, the bigger the buttons appear, with a maximum size of twice their original dimensions. This contributes to a feeling of responsiveness before performing the actual selection. According to Fitts' law, it also decreases the time to hit the target area.

We provide visual feedback on almost all interactive elements the user is pointing at by changing their background color to red. The right side menu can be opened by only pointing at it; the carousel buttons work the same way as in the *Touch* modality. In order to view a tooltip, the user needs to point at an element for 200ms.

3.2 Implementation

We implemented *Here Comes the Sun* as a web application, using plain HTML, JavaScript and CSS. A Python Flask server captures interaction data and provides three different endpoints for the three interaction modalities *Mouse*, *Touch*, and*Fich*.

To track the user's finger during interaction with *Here Comes the Sun*, we use a Leap Motion Controller. Our implementation is based on previous work by Aslan et al. [2], mainly their Leap Motion calibration code. It enables us to map the user's finger position from the Leap Motion space to the screen position. We make use of the *Leap Motion Desktop v2* software development kit [16] as well as *LeapJS*, the official JavaScript client for the Leap Motion controller[17]. We strived to keep the *Fich* implementation as generic as possible so that minimal effort is required to enable *Fich* support in other applications.

In order to detect interactions with UI elements, we compute the corners of the bounding box for each element during initialization. This allows us to determine whether the user is currently pointing at an element. To assess whether the user is increasing or decreasing the distance between his finger and the element he is pointing at, we compare the finger's z-values at the beginning of the *fingerHover* event to the current z-value. Tooltips are displayed whenever the user points at an element for 200ms while keeping the finger within a 5px square, which serves as a threshold to prevent accidental interactions. This check is carried out within the update loop of the Leap Motion, typically 60 times per second in modern browsers.

Similar to common JavaScript handlers for mouse and touch events, the developer of an application with *Fich* support can override the default behavior of *Fich* events, such as *fingerHover* or *fingerHold*, for all UI elements in an additional configuration file.

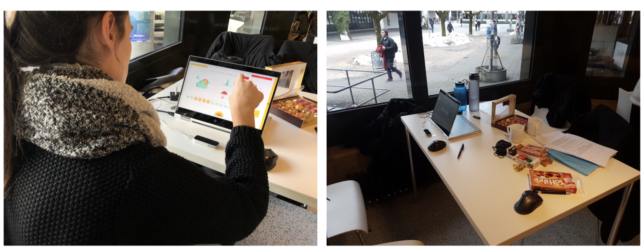

Figure 2: Setup of the user study.

4 USER STUDY

We divide our research goal into two research questions according to the goal-question-metric approach [8]: *(a) What impact does Fich have on user experience compared to the state of the art input alternatives Mouse and Touch? (b) Does Fich support serendipitous discoveries?* We designed the study as within-subjects. Every participant went through each of the previously described interaction modalities (i.e., *Mouse*, *Touch*, and *Fich*) in *Here Comes the Sun* once. We counter-balanced the order in which participants used the three input techniques to address carry-over effects of recognition and boredom. In order to measure our research questions, we define the metrics presented in the following sections.

4.1 Measuring User Experience

To address the first research question, we use the *User Experience Questionnaire* (UEQ) [15], a self-defined metric, and qualitative questions.

4.1.1 User Experience Questionnaire. The UEQ is a research framework that distinguishes user experience into three main categories: perceived ergonomic quality, perceived hedonic quality, and perceived attractiveness of a product. Ergonomic quality is subdivided into three factors: perspicuity, efficiency, and dependability. Perceived hedonic quality consists of stimulation and novelty.

4.1.2 Qualitative Questions. To explore participants' thoughts and cover aspects that cannot be measured quantitatively, we additionally asked (open ended) qualitative questions. We requested participants to state what they liked and did not like about each of the three scenarios and allowed them to answer in free text. Furthermore, we asked them to pick their favorite interaction technique. To find out whether pre-touch interaction has the potential to be employed in a real-world scenario, we asked users if they agree with the statement that they would like to use this new interaction possibility on their own devices. The corresponding 6-point Likert scale reached from "*not at all*" to "*totally*".

4.2 Measuring Serendipitous Discoveries

Serendipity is about making "*accidental discoveries*" [19]. Applying this to the context of User Experience, we define serendipitous discoveries as "accidentally discovering new elements in the user interface of the application". We are not aware of a questionnaire measuring the serendipity of an application. To answer our second research question, we measured a "UI Exploration" score and included related qualitative questions in our interview. We believe that serendipitous discoveries are beneficial to users of a new user interface, helping them in an implicit manner to get to know the user interface.

During the interaction with *Here Comes the Sun* we kept track of the number of UI elements the user has discovered. The first time a distinct item has been viewed by the user, we set a corresponding boolean flag. "Discovering" the same element twice does therefore not increase serendipity since it has been explored previously. If the user has looked at many different elements in the UI, we assume that the interaction modality used has fostered serendipity. We evaluate differences between the three interaction techniques by comparing these UI exploration scores for each setting.

To cross-validate our UI exploration metric, we inquired more information from our participants. We posed the statement that the new interaction technique of *Fich* has supported them in discovering interactive elements in the interface. Users provided agreement scores to this statement using a 6-point Likert scale, ranging from "*not at all*" to "*totally*".

4.3 Participants

We conducted the user study at two University campuses. Half of the locations were busy cafeterias, the other half secluded workspaces. All 42 participants (22 female, 21 male, 1 non-binary) were selected randomly. 30 out of 42 participants (71%) were in the age group of 18 to 24, 10 (24%) were aged between 25 and 34, and 2 participants

(5%) over 50. 100% of the users reported they were using their smartphones multiple times a day. 71% responded they were using their personal computer or laptop several times a day, with 17% using it daily and 12% multiple times a week. We conclude that all of the participants are familiar with touch devices and computers.

4.4 Procedure

First, participants filled out a demographic questionnaire. Next, we asked them to sit down in front of the study setup, a Microsoft Surface with an integrated touch-screen, hooked up to the pre-calibrated Leap Motion Controller. Figure 2 shows the study setup and a participants interacting with *Here Comes the Sun*. This setup was used for all three interaction modalities.

Since we evaluated three conditions, there were six different possible orderings. We performed each ordering exactly seven times to account for ordering effects. Before letting our participants try out *Here Comes the Sun*, we introduced the app with the following description: "There are three fictional cities with generated weather data. Your task is to choose a city and a specific day on which you'd like to go on vacation there based on your weather preferences." We assured the users that there were no wrong or right answers and that their decision should only be influenced by personal opinion. The reason we gave them a specific task was to avoid situations where the participant would aimlessly play around with the app.

Before each scenario, we briefly told the participants which setting they were about to test. In the case of the *Fich* modality, we briefly described the interaction technique. We explained that whenever their index finger was hovering in mid-air in front of the screen, it was tracked, causing a cursor to follow their movements. To select an element, users still needed to touch the display. We then let the participants figure out how to interact with this technique on their own.

Participants spent as much time as they wanted in each setting, ending one session by choosing a certain city and day of the week. After every condition, we presented them with the UEQ. After all three conditions filling out the UEQ three times, participants filled out a concluding questionnaire containing the "qualitative" questions. We thanked the participants for their time.

5 RESULTS

5.1 User Experience Questionnaire

The UEQ measures user experience along the three dimensions Attractiveness, Pragmatic Quality, and Hedonic Quality [15]. Each scale reaches from -3 ("*horribly bad*") to +3 ("*extremely good*"), though the questionnaire's authors stress that in real work applications values above +2 and below -2 are hardly being observed. Values greater than +.8 can be evaluated as a positive user experience, whereas values less than -.8 indicate a negative user experience. The mean values over all participants are depicted in Figure 3 and 4, comparing the study's three conditions *Mouse*, *Touch*, and *Fich*. For each of the three main categories, we performed a one-way repeated measures ANOVA. A Greenhouse-Geisser correction was applied where Mauchly's test indicated that the data violated the assumption of sphericity. For pairwise comparisons, we used a Bonferroni correction to maintain an alpha level of .05.

Regarding Attractiveness, we observed a slightly higher mean in the *Touch* setting (1.60) compared to *Mouse* and *Fich* (1.12 and 1.16, respectively). The ANOVA did not reveal any statistically significant differences.

Measuring Pragmatic Quality of *Fich*, *Mouse*, and *Touch* yielded means of .56, 1.78, and 1.88. The statistical analysis pointed to a significant difference in the means ($F(1.625, 66.612) = 29.268$, $p < .0005$, $\eta^2 = .417$). We performed a pairwise comparison and found *Fich's* Pragmatic Quality to be rated significantly lower than Pragmatic Quality of both *Mouse* ($p < .0005$) and *Touch* ($p < .0005$).

We observed Hedonic Quality scores to be the highest for *Fich* (1.95), followed by *Touch* (.42) and *Mouse* (-.44). The ANOVA determined that the means differ statistically significantly ($F(1.847, 75.713) = 67.500$, $p < .0005$, $\eta^2 = .622$). A pairwise comparison revealed significant differences between all three groups ($p < .0005$ each).

5.2 Summary of User Comments for Each Modality

5.2.1 *Mouse.*

When asked what they liked about interacting by mouse, participants often named characteristics such as "fast", "familiar", "reliable", and "easy to use". One person stated that he "felt in control" using a mouse. 19 out of 42 participants gave an answer to the question of what they disliked in this scenario. Negative associations respondents brought up the most were "boring" and "outdated".

5.2.2 *Touch.*

Advantages named when interacting by touch were similar to those named in the *Mouse* condition. Four participants described touch interaction as "intuitive". Eight participants stated things they did not like. Two of them mentioned that they had a hard time discovering the tooltips.

5.2.3 *Fich.*

Users liked about *Fich* that it is "novel", "cool", "exciting", "interesting", "fun to use", and "innovative". During the user study, we observed some participants smiling or even laughing using *Fich*. Four people explicitly mentioned that access to tooltips was easy. One participant wrote that scaling the buttons depending on the finger-to-screen distance is a "brilliant solution". 33 participants gave answers when asked what they did not like about *Fich*. Almost all answers concern the tracking of the finger position. They experienced it as "inaccurate", "not smooth", "slow", and "buggy". Two participants would have liked to select elements by clicking in mid-air.

5.3 Analysis of Serendipitous Discoveries

In order to determine the effect of *Fich* on serendipitous discoveries, we evaluated our metric *UI Exploration* as well as the additional qualitative questions.

5.3.1 *UI Exploration Scores.*

In our experiment we measured the percentage of distinct elements in the user interface that were opened (i.e., "mouseover" event was triggered) during interaction within each setting.

While users discovered 73% of UI elements when interacting with *Fich*, they only came across 44% and 25% of elements (in average) for the *Mouse* and *Touch* settings. We thus conclude that *Fich* fosters "serendipity" by enabling the user to discover more elements in the

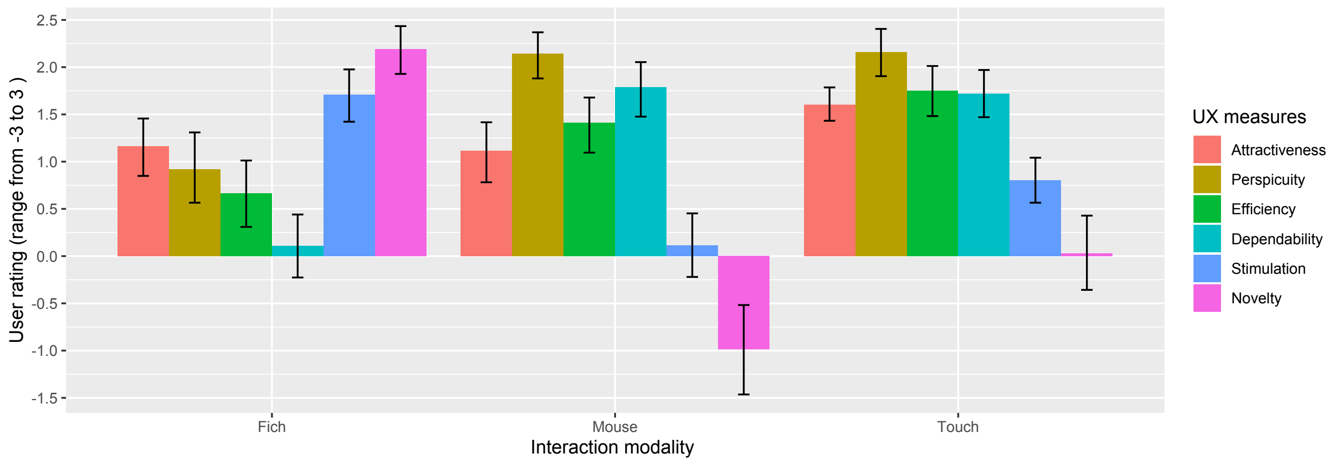

Figure 3: Results of the UEQ questionnaire for all factors. Error bars denote 95% confidence intervals.

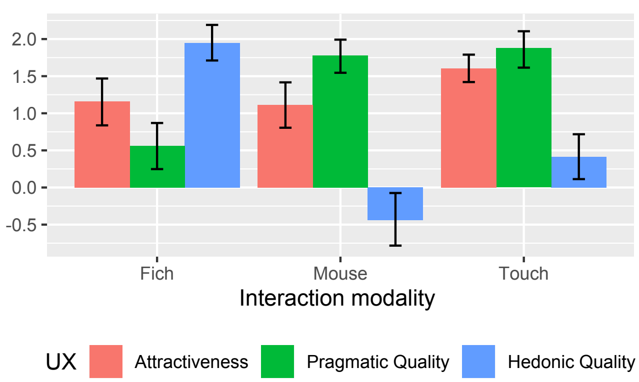

Figure 4: Results of the UEQ questionnaire for the three main categories. Error bars denote 95% confidence intervals.

UI, and therefore learn more about the application at hand. This is achieved through tooltips that are easy to open as well as UI elements that increase in size upon an approaching finger.

The low UI exploration score for the *Touch* setting confirms our initial hypothesis that tooltips on *Touch* are neither mature nor easy to use. It is inconvenient to perform the long-press action that commonly triggers tooltips on touch interfaces, which is an innate impediment of *Touch*. Our analysis on UI exploration confirms that *Fich* can overcome this issue.

The increased pragmatic quality of traditional input devices thus comes with a cost: less support of serendipitous discoveries and less understanding of the application one interacts with.

We believe that the higher number of elements explored in the *Fich* setting is partially attributable to people spending nearly twice as much time exploring the interface when they were asked to use *Fich* compared to both *Mouse* and *Touch*. However, if people enjoy this interaction (as confirmed in Section 5.1), this increased interaction duration is not necessarily negative.

5.3.2 Perceived Serendipity. Besides measuring UI exploration scores as a proxy for serendipity we also asked our users directly whether *Fich* has helped them find interactive elements in the weather application. Possible results ranged from "*not at all*", equivalent to a value of 1, up to "*totally*", corresponding to a value of 6, on a 6-point Likert scale. The average of all responses is 4.00 (SD=1.7). We conclude that participant tend towards agreeing that *Fich* supported serendipitous discoveries.

5.4 User Preferences and Acceptance

5.4.1 Fich's Potential on Own Devices. We asked our users whether they would like to use *Fich* on their own devices. Our intention was to get initial insights into user acceptance of *Fich* . They answered on a 6-point Likert scale ranging from "*not at all*" to "*totally*". The average value we determined from these answers is 3.16 (SD=1.6), i.e., lower than 3.5. This means that there is still a slight aversion towards integrating *Fich* in everyday life. We believe this is due to technical limitations of *Fich*.

5.4.2 User Preferences. 52.5% of users reported *Touch* to have been their favorite modality. 27.5% claimed they preferred the *Mouse* and 20% liked *Fich* the most. This confirms our own impression that *Fich* has to be less buggy in order to make it to the mass market. The much lower score for *Mouse* in comparison to *Touch* is also noteworthy. Computer mouses have been around for a much longer time than touch screens, which might explain why users have gotten tired of interacting with mouses and deem touch screens more intuitive. A similar fate might apply to touch screens, once interaction techniques such as *Fich* mature. Once we can improve the pragmatic quality of *Fich* by making it more reliable, its popularity might overtake the acceptance of *Touch*.

6 DISCUSSION

Touch screen interfaces have been the dominant interaction technique on mobile consumer products (especially mobiles) on the market in the last decade. We have motivated our research by arguing that there are limitations in today's touch screen interfaces, which can be addressed by implementing novel techniques, such as *Fich*, interweaving touch and mid-air sensing. In fact, more and more contexts (e.g. automotive) and hardware (e.g., digital pen) are starting to utilize a combination of mid-air input and touch/haptics. We believe that *Fich* has the potential to benefit a larger number of different consumer applications and devices, including private mobile phones, laptops, desktop PCs, or even public displays, e.g. in train stations or museums.

In our study *Fich* was perceived as less pragmatic than *Mouse* and *Touch*. The traditional input devices have been known for a long time and are thus very mature. *Fich* has just emerged and might be rated less pragmatic due to technical limitations, as indicated by the free text answers of our participants in Section *5.2*. From these results we can also derive that our users enjoyed using *Fich* much more than *Mouse* and *Touch* on a hedonic level. We believe that there is huge potential for *Fich*, once pragmatic issues, induced by current limitations associated with mid-air sensing quality, have been overcome. Considering the ubiquity of touch devices and the utility gained with the integration of *Fich*, we hope to have built an interaction that is "in style" [10], or will be soon. We believe that limitations of touch interfaces are being stressed today and the emergence of new media including augmented reality will push the need for technical innovation in mid-air hand- and finger-sensing, and new interaction paradigms. An introduction of *Fich*-related concepts to the mass market in the not too distant future seems likely. Of course, preferred daily human-computer-interaction might be biased depending on age: E.g., mobile touch devices could be preferred by younger participants whereas traditional mouse interaction could be perceived more familiar and efficient by mid-age participants. For this reason, we invited participants from different age groups and an age range from 18 to 55.

Contribution. We have introduced *Fich* as a new technique to enable effects similar to mouseover for touch interfaces and described the *Here Comes the Sun* application which integrates *Fich*. Our research supports the improvement of hedonic qualities of UX when exploring interactions with a single proximity (in 3D) sensitive touch target on the screen, as reported by Aslan et al. [2]. We have extended their results by demonstrating that hedonic qualities are indeed improved even when there are multiple interactive elements on the screen. Furthermore, we compared the user experience of *Fich* with state of the art interaction techniques. We observed that when multiple proximity-sensitive touch targets are on screen, the pragmatic qualities in UX decrease significantly compared to both *Mouse* and *Touch*. Therefore, our study revealed both significant beneficial and adversarial effects when a (3D) proximity sensitive technique is integrated in an everyday application and UI consisting of multiple interactive touch targets. Finally, we explored how *Fich* as a proximity-sensitive technique supports serendipitous discoveries, which we found to be a potentially unique benefit of this interaction technique.

6.1 Limitations

In our evaluation, we used the same application and study setting for three different interaction modes. Participants therefore might get used to the app's user interface and structure. This may have a negative impact on the exploration for the second and third interaction as well as shorter usage durations. To cope with this problem, we counter-balanced the order of interactions.

Considering serendipitous discoveries, our research should be considered as an initial study. Future research is required to increase our understanding of when serendipitous discoveries are welcome and when a potential system should decrease support for serendipitous discoveries (e.g., if there is a risk that "hover effects" may be perceived as annoying).

6.2 Future Work

Based on our own experience with *Fich*, and discussions we had with study participants, we have identified multiple potential future use cases for *Fich*:

Live Translator. Fich might be used as a live translator. When the user hovers over text in a foreign language, we could translate it to some other language and display the resulting text, e.g. in a tooltip. This could be valuable for ad-hoc translations, especially in the context of mobile and desktop environments.

Screen Magnifier. Similarly to the live translator, we could use *Fich* as a screen magnifier. When the user hovers over certain elements or text in the user interface, we could trigger a screen magnifier, zooming in on these elements, being useful especially for elderly people who have difficulties identifying small items on the screen.

Audio Feedback. Fich could be augmented with audio feedback. Hovering over certain elements on the screen could trigger audio responses. This could be viable in cumbersome interaction contexts, e.g. for navigating interfaces while driving a car, particularly as an alternative to speech input. It could also enable blind people to interact with their touch devices more easily.

Learning Application. One participant suggested that the vivid visual feedback enabled by *Fich*-based interaction would be useful in teaching applications, arguing that *Fich* could help students to stay focused — supported by our finding that *Fich* fosters serendipitous discoveries.

7 CONCLUSION

We presented *Fich*, a novel interaction technique leveraging 3D proximity sensitive *pre-touch* to improve interaction with touch devices. We effectively integrated *Fich* into an application's graphical user interface, displaying additional information and expanding the application's interaction space. In doing so, we overcame some of the shortcomings of traditional touch screens, which lack an appropriate equivalent to mouseover effects seen in mouse-based environments like PCs or laptops. We reported on a user study with 42 participants. With the help of a lifelike, custom-built weather application, we showed that *Fich* is significantly superior to traditional input methods like *Mouse* or *Touch* considering the hedonic quality of UX, but significantly inferior considering the pragmatic quality of UX. Participants' comments, as well as our own observations, indicated that results in pragmatic quality are at least in part attributable to the limitations of today's finger sensing technologies. We hope that our research helps to improve our understanding of limitations and potentials of pre-touch techniques and that it will guide future research efforts towards bringing this novel interaction technique to the mass market.

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