Exploring Tapping with Thumb Input for Flexible Tablets

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Abstract

Flexible displays offer new interaction techniques, such as bend gestures, but a little work has been done to support touch input, the most common input for handheld displays. In this paper, we explore touch input using the thumb of the holding hand, and compare it for different tapping tasks, between a flexible and a rigid tablet. We present initial design guidelines to use touch input with thumb in flexible devices. Our result suggests that users can perform tapping interaction using thumb input in both rigid and flexible devices with similar accuracy, and they prefer holding the display on the side or the bottom corner over the bottom center.

Author Keywords

Deformable UI, flexible displays, touch input, tapping

ACM Classification Keywords

H.5.2 User Interfaces: Input devices and strategies.

Introduction

The most common interaction method for present-day tablets is touch input. While the rigid tablets can take the full advantage of touch input, flexible devices currently provide limited support for touch interaction, as flexible displays may not always provide adequate normal force to support touch input [2]. The distribution of normal force depends on the way they are held (e.g. on the corner or the side, with one hand or two). Dijkstra et al. [2] showed that the holding hand provides the structural support required for pointing tasks using the other hand.

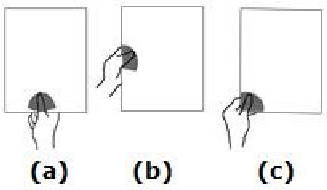

Figure 1. Three common hold positions: (a) bottom center, (b) side center, (c) bottom corner

Extending their observations, we noticed that the holding hand may provide sufficient normal force to support touch input in the adjacent region of that hold. As several studies revealed user preference of touch input using thumb in rigid handheld devices [4, 5, 11], we were interested in maximizing the capability of holding hand in flexible device context. Hence, we focused in this study on touch input using the thumb of the holding hand in flexible tablets. In addition to providing standalone thumb input, we believe it can be particularly useful when combined with bend interactions [1, 6, 7]. To bend a tablet-sized display, users typically use both hands, one to hold the device and the other one to bend it [7]. By using thumb input, the holding hand can add an additional dimension to bend interactions, bringing in the advantages of bimanual interactions to flexible display [8, 9, 11].

We compared the performance and preference for thumb tapping interaction between a flexible and a rigid tablet. We evaluated both dominant and non-dominant hands, with 3 hold positions. We provide initial design guidelines for tapping interaction using the thumb of the holding hand for tablet-sized flexible displays.

Background

Of the five common holds for rigid handheld devices [11], three use the thumb of the holding hand for touch input: bottom center, bottom corner and side center (Figure 1). Dijkstra et al. also used these three holds with flexible display [2]. Wagner et al. evaluated tapping with both thumb and other fingers in rigid tablets, and showed that thumb outperformed fingers in both landscape and portrait mode [11]. Parhi et al. suggested that the target size for thumb use should be at least 9.2mm for single target tasks and 9.6mm for multi-target tasks [10]. They also showed that, in a 3x3 region matrix, the center target is the most preferred, which is also supported for larger number of targets [3]. ThumbSpace introduced a mechanism to reach the far targets of the screen using thumb, by using a ‘radar-view’ which can be triggered within the reach of thumb allowing users to access all locations on the screen [4]. The authors suggested that this superimposed touchpad cannot replace direct touch in standard touch screen devices, but can improve the touch interaction in handheld devices when used as an additional input dimension with direct touch.

When investigating combining deformation and touch in a flexible handheld device, Kildal et al. found a preference for touch on the front of the device, as users could use their thumb instead of index finger [6]. In FlexView, Burstyn et al. proposed flexible scrolling methods, including utilizing touch input using the holding hand’s thumb for vertical and horizontal scrolling [1]. Their findings suggest that the thumb has a more comfortable range of vertical motion afforded by gripping the side of the display. Their results suggest that by augmenting touch with bend in parallel improves user experience in flexible devices.

Interaction Techniques

This study focuses on thumb interaction with the holding hand. With each hold, the thumb can reach a small area of the display. Figure 1 highlights this area for each hold position. As users like to reach a target

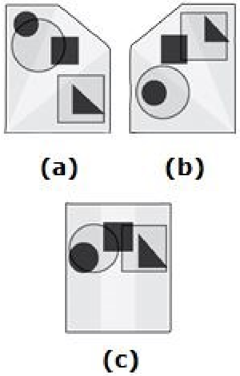

Figure 2. Layout for (a) side center and bottom corner holds for left hand; (b) side center and bottom corner holds for right hand; (c) bottom center hold for both hands.

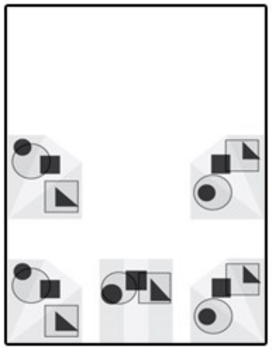

Figure 3. All touch regions as displayed on the prototype.

with the thumb naturally extended, and that the targets need to be approximately 1cm wide [10], this restricts the number of available targets. To accommodate for different thumb length, we designed tapping zones, triangular or rectangular shapes to maximize tapping opportunities. With thumb input, we are interested to investigate how many tapping regions per hold users could handle comfortably. We conducted an informal study with 5 participants: 3 had difficulty distinguishing more than 3 regions, and 2 mentioned not being comfortable with more than 2 regions. This preliminary study identified the need to explore this further.

Study

We designed a study to evaluate the tapping abilities of the thumb, by comparing a flexible and a rigid prototype. We evaluated tapping interaction in three common holds, with each the dominant and the non-dominant hand, as user preference and performance for tapping interactions may vary between two hands. Finally, we assessed two sets of tapping regions. 21 participants (8 females) completed our study (Mean Age = 24.1yrs). They received $10 gift card.

Task & Design

We had total six factors in our experiment: flexibility (rigid or flexible), number of tapping regions per hold (2 or 3), hold positions (bottom corner, side center, and bottom center), hand (dominant or non-dominant), active regions for two tapping regions per hold (closest region to the index finger, furthest to the index finger), and active regions for three tapping regions per hold (closet, middle, furthest). Three factors, flexibility, hand, number of tapping region per hold, were counter-balanced and the rest three were randomized to avoid carryover effects.

To identify tapping regions, we used printed shapes (Figure 2, 3) over of dynamically projections to avoid visual occlusion. We used filled black shapes for three regions and outlined shapes for two regions. We confirmed these overlapping tapping regions with 5 pilot participants. The current target was projected in the middle of the display, and the experimenter verbally told the participants about the type of shape (black or outline), the hold and which hand to use for interaction. Touching anywhere in the relevant hold region would activate the task. Each task comprised of tapping in three holds with one hand using either the flexible or the rigid prototype. We measured time to reach a target (time between when the target is displayed and when the user taps the relevant printed shape), and number of errors (tapping a wrong target). Participants were first trained on the task, and then performed 5 trials per combination of factors, for a total 300 trials. After each task, participants filled out post-test questionnaires where we used 5-point Likert scale (1 = Easy; 5 = Difficult).

Prototype

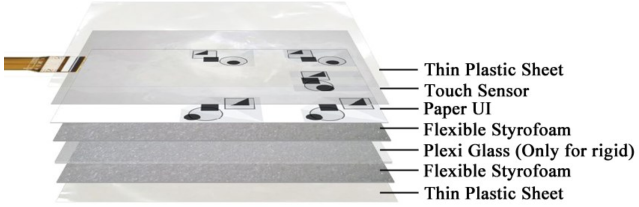

Figure 4. Exploded view of our prototype.

Our prototype was composed of 6 layers (3.25 mm), with an extra layer (2mm) for the rigid condition (Figure 4). A paper was placed on top to visualize the fixed tapping regions and hold region (Figure 3). We

	Error (no. of errors)		
	Factor	**Level**	**Mean (SD)**
A1	Flexibility	*Flexible*	0.09 (0.34)
		Rigid	0.08 (0.31)
	Hand *	*Dom.*	0.10 (0.36)
		Non-Dom.	0.07 (0.28)
	Hold	*Bottom Corner*	0.08 (0.29)
		Side Center	0.10 (0.33)
		Bottom Center	0.09 (0.34)
A2	No. of tapping regions per hold	*Two*	0.10 (0.25)
		Three	0.08 (0.17)
A3	**Two tapping regions per hold** *	*Closest*	0.06 (0.32)
		Furthest	0.13 (0.39)
A4	**Three tapping regions per hold** *	*Closest*	0.08 (0.30)
		Middle	0.06 (0.26)
		Furthest	0.11 (0.34)

Table 1. Quantitative results for tapping error. Bold indicates significance.

used a 10.06”x7.17” flexible Zytronic touch sensor to detect touch input [12]. We used a Styrofoam layer beneath the touch sensor to provide insulation, to help users avoid accidental activation of touch from the back of the sensor. Two layers of thin plastic sheet wrapped the prototype from front and back. We used a pico-projector to create a display on the prototype.

Results

We performed a repeated measure ANOVA (A1), using the factors: flexibility (rigid, flexible), hand (dominant, non-dominant), hold (bottom corner, bottom center, side center). None of them had significant impact on time to reach the target (Figure 5). Only hand was significant for the number of errors ($F_{1,20}$ = 12.518, p<0.01). Users made more errors with the dominant hand than with their non-dominant hand (Table 1).

We performed a second ANOVA (A2) using only the number of tapping regions per hold (two, three) as factor. For this ANOVA, we averaged the tapping region measures of two and three tapping regions per hold, for each trial, so we could compare the same number of measures. We found significance on time ($F_{1,20}$ = 27.735, p<0.001): users were faster with two tapping regions than three tapping regions per hold (Figure 5).

We performed a third ANOVA (A3) on the active regions of two tapping region per hold. We found significance on both time ($F_{1,20}$ = 13.621, p<0.01) and error ($F_{1,20}$ = 8.475, p<0.01). Users were faster tapping the closest region (M = 962 ms, SD = 454) than the furthest (M =1038 ms, SD = 521). The closest region also had lower number of errors (Table 1).

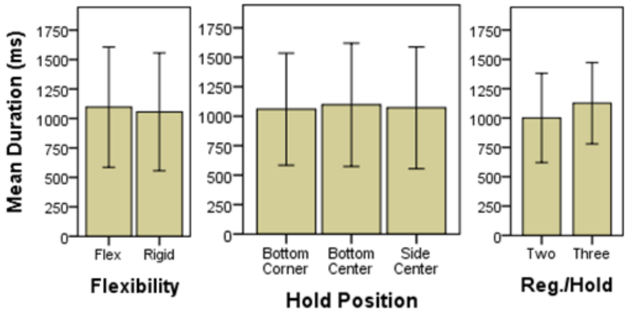

Figure 5. Mean tapping duration for flexibility, hold position and number of regions per hold. Error bars represent +/- 1SD

We ran a fourth ANOVA (A4) to detect the effect of active region of three tapping regions per hold. It had significant impact on time ($F_{2,40}$ = 37.293, p<0.001), and error ($F_{2,40}$ = 5.732, p<0.01). The users took the least time in the middle region (M = 1044 ms, SD = 416), then respectively the furthest (M = 1120 ms, SD = 506), and the closest region (M = 1213 ms, SD = 578). They made most errors in the furthest region, then in the closest region, and the middle region.

We performed a Friedman test using all the factors. User preference significantly varied for the factors: flexibility (χ^2 = 10.121, p<0.01), hand (χ^2 = 10.195, p<0.01), hold (χ^2 = 170.629, p<0.001), number of tapping regions per hold (χ^2 = 12.045, p < .01), and active regions of three tapping regions per hold (χ^2 = 6.743, p<0.05). Users preferred the rigid version over the flexible one, and preferred two tapping regions per hold over three (Table 2). For three regions per hold, the middle region had the most preference, then the closest and the furthest regions. The bottom center was the least preferred hold position while the side center and the bottom corner had close average ranks. The

Factor	Levels	Ranks
		Mean (SD)
Flexibility *	*Flexible*	1.69 (0.97)
	Rigid	1.62 (1.01)
Hand *	*Dom.*	1.61 (0.98)
	Non-Dom.	1.70 (0.99)
Hold *	*Bottom Corner*	1.43 (0.78)
	Side Center	1.40 (0.72)
	Bottom Center	2.13 (1.21)
No. of tapping regions per hold *	*Two*	1.56 (0.89)
	Three	1.73 (1.04)
Two tapping regions per hold	*Closest*	1.52 (0.90)
	Furthest	1.54 (0.89)
Three tapping regions per hold *	*Closest*	1.78 (1.05)
	Middle	1.64 (0.98)
	Furthest	1.78 (1.08)

Table 2. Qualitative results for tapping interaction. Bold indicates significance.

dominant hand had a higher preference than the non-dominant hand.

Discussion and Initial Design Guidelines

Flexibility: Users preferred the rigid version of the prototype over the flexible version, because the rigid one provided better support to hold the device, according to several participants. This result is expected, as it is easier to touch a rigid surface than a flexible one due to the constant normal force available. However, the two rigidities had comparable performance (duration and error). These results are encouraging, and indicate the potential of thumb input, to provide suitable touch interactions in flexible display.

Holds: Participants had similar performance across all holds. However, user preferred the side center and bottom corner hold, but they felt less comfortable with bottom center hold. We expected to find the side center and bottom center holds to have similar preference, as the hold position is physically identical, with a similar angle (see Figure 2). On the other hand, bottom center hold is different: it requires a perpendicular hold, which users found uncomfortable, and the hardest to use. For tablet-sized flexible displays, we recommend using bottom corner and side center for tapping interaction.

Tapping Regions: Users were faster tapping two tapping regions per hold than three. This is consistent with their preference results. However, the error rates did not vary significantly between two and three tapping regions per hold. As the accuracy was similar for distinguishing adjacent tapping regions of both two and three regions per hold, we suggest that both two and three tapping regions can be integrated. For three tapping regions per hold, user performance and preference were highest at the middle region. For two tapping regions per hold, though users made more errors and took more time when using the furthest region than the closest one, they did not show any variation in the preference between the regions. For three tapping regions per hold, we recommend assigning the most frequently used tapping region to the middle region.

Hand Dominance: We obtained contradictory results when it comes to hand dominance: performance, participants were less accurate with their dominant hand (more errors), yet they preferred using their dominant hand. We believe that this means they can use both hands well. As most users will use their left hand to hold the device, this will allow a majority of users to make use of their right, dominant hand for more precise tasks, without penalizing the left handed users. However, we recommend allowing touch input using the thumb of the holding hand on all tapping regions.

In addition, some users mentioned a preference for two tapping regions per hold for the non-dominant hand but they were equally comfortable for two and three tapping regions when they used their dominant hand. This confirms their perceived performance accuracy with their dominant hand. As we recommend providing thumb interaction for both dominant and non-dominant hand, we suggest using three tapping regions per hold for the dominant hand and two tapping regions per hold for the non-dominant hand.

Conclusions and Future Work

In this study, we explore a set of touch interaction techniques using the thumb that maximizes the use of the holding hand in a flexible display. We evaluated our interaction techniques in prototypes of different rigidities. We found that users perform similarly in our rigid and flexible prototype, preferred to hold the device on the side or the bottom corner, and that for each hold, the user can handle both 2 and 3 targets regions. Therefore, we believe that using the thumb of the holding hand for touch input can bring the benefits of touch interactions in flexible displays.

Three main research directions can stem from this work. It is imperative to implement thumb touch input in a variety of applications. It would be interesting to evaluate whether thumb input is best for direct touch input, or to act as an augmented touchpad, according to the requirement of user interface. Second, we will expand the interaction techniques beyond tapping, to include swiping for instance. Finally, it would be worthy to investigate how thumb touch input and bend gestures can complement each other in bimanual simultaneous interactions in a flexible display.

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