Exploring the Effects of Size on Deformable User Interfaces

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Abstract
Deformable user interfaces have received increasing attention in recent HCI research. However, the effect of device size on deformable user interfaces has not been studied yet. This study is aimed to investigate how the size of a deformable device affects users' interaction behavior and preferences. We observed users interacting with deformable mockup displays of two different sizes. Overall, 36 participants provided 769 user-defined gestures for 11 basic commands. We compared and discussed users' preferences toward two different sizes of deformable devices. We also covered user-defined gestures and patterns of use for each device size. As a preliminary study for understanding form factors for designing deformable user interfaces, this study clearly show that the device size is an important factor to consider when designing mobile devices which can be deformed.

Author Keywords
Deformable user interface; flexible display; user interface; organic user interface

ACM Classification Keywords
H.5.2 [Information Interfaces and Presentation]: User Interfaces.

Introduction

Deformable user interfaces have received increasing attention in recent HCI research. Up to now, the feasibility of employing deformation mechanism as a new interaction method, such as bending and twisting, has been explored [1,2,3,5,7,8,10,11]. Based on this idea, more practical applications were developed for various domain including phone [5], media control [7], and E-book reader [11]. All of those prototypes were designed with a mobile size so that users can hold and manipulate device with both hands.

However, so far, there is no study that provides implications regarding the size of device. Although the device size is a very simple factor, it might change users' interaction behaviors and preferences.

To address this, as a preliminary explorative study, we observed users interacting with deformable mockup displays of two different sizes. We tried to understand how the size of a deformable device affects users' interaction behavior and preferences. In all, 792 user-defined gestures from 36 participants were analyzed for 11 basic commands. The results show that the device size is an important factor in designing deformable user interfaces.

Related Works

The early studies tried to look for possibilities of deformable user interface with simple technologies. *Gummi* [8], is the first such attempt to design a device with a proper interface style based on the unique physical properties of flexible electronic system. The authors developed a bendable device and explored various methods of menu selection, and zooming on a map. In *PaperWindows*, Holman et al. [4] suggented a projection based computing environment. This allows the user to capture the physical affordances of paper in the digital world. Gallant et al. [2] designed foldable user interfaces, a prototyping tool for flexible displays. Watanabe et al. developed *Bookisheet* [10], an interface for browsing content that adapts the metaphor of turning a page of a book. Applying these concepts, users could easily and interestingly control digital contents.

However, those early studies were mainly focused on technological aspects, and the part opened to the user was the evaluation process which is for convincing validation of the new techniques. Consequentially, several works have done based on a user-centered approach to understand users' need toward deformation based interaction regardless of the current technical issues. Herkenrath et al. [3] tried investigate the effects of using the deformation concept as an input in mobile devices, and to provide a design guideline for deformable user interfaces. Lee et al. [6] tried to draw an implication that could be more generally applied to interactions based on deformation by observing users' behaviors with various materials and commands. The main finding is that when a display material gave more freedom from deformation, the level of consensus of gestures among the users as well as the intuitiveness and preferences were all enhanced. Dijkstra et al.[1] conducted a study to understand the effects of structural holds and rigidity of a flexible display on touch pointing and dragging performance. Their results suggest that structural force distributions in a flexible display affect the Index of Performance of both pointing and dragging tasks.

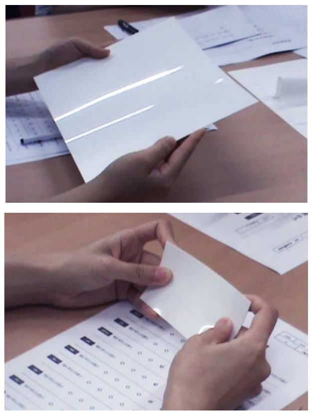

Figure 1 A The large-sized device (left, 210 x 297 mm, A4-size) and the small-sized device (right, 59 x 115 mm, iPhone-size) that are used in this study.

Based on this knowledge, more practical applications were developed for various domain including phone [5], media control [7], gaming [14], and E-book reader [11]. Lahey et al. presented *PaperPhone* [5], a smartphone-like flexible E-Ink prototype. With this prototype, they evaluated the effectiveness of various bend gestures in executing a set of tasks with a flexible display. Lee et al. designed *FlexRemote* [7], and explored the possibility of using deformable user interfaces as a new input method to remote control. They selected eight basic commands to control TV and design deformation-based gestures for each command. Ye et al. [14] proposed *Cobra*, a handheld flexible device for computer games to provide a highly intuitive mobile gaming experience. The game uses bends as input methods. Wightman et al.[11] presented recommendations for the design of flexible electronic book readers, based on an empirical evaluation of form factors and input techniques in a page navigation task. To address this, they designed and implemented *BendFlip*, a flexible E-reading device.

In these existing works, flexible prototypes were designed with an arbitrary size. However, there is no literature that gives implications regarding device size. Although Wightman et al.[11] pointed out size issues for designing their flexible E-book reader, they did not provide implications regarding device size.

Study Methodology

To understand the effect of size on deformable user interfaces, we conducted a study in which users were asked to elicit gestures that could be used to conduct standard computing tasks with mockup deformable displays as input devices. This is the same approach with the previous work conducted by Lee et al [6]. By using mockup device, we could only focus on the variable of size. In general, the method of this study was based upon the previous gesture elicitation studies [6,12,13]. Detailed study design rational is discussed in the prior work [6].

Devices. We made two mockup deformable devices of two different sizes (Figure 1). In our prior work, we emulated the future information devices measuring 210 x 297 mm, the same size as a sheet of A4 paper. We used this as a *large-sized* deformable device for this study. Add to this A4-sized mockup device (large-sized device), we made the *small-sized* handheld devices measuring 59 x 115 mm, the same size as the iPhone4. We assumed that both sides of the devices are capable of displaying information. Both devices are made of thin flexible plastic, which is the most similar type of material to current flexible displays.

Commands. For the commands we presented, 11 application-agnostic basic commands were derived from the previous studies [4,6,8,10,11,13]: *zoom-in, zoom-out, next, previous*, and *scrap* (scrap current page to scrap folder) and common features such as *on, off, delete, open, close,* and *copy to other device*, 11 commands in total were selected for the study

Participants. In total the study included 36 participants with an average age of 28.1 (from 19 to 39, SD=4.12), 18 of them were men and 18 women. All of the participants were right-handed college students with no previous experience with flexible interfaces.

Moderating and Procedure. Two different sizes and 11 commands were used as independent variables, meaning that each participant was supposed to define gestures for 22 different situations. Given 36 participants, a total of 792 individual motions were

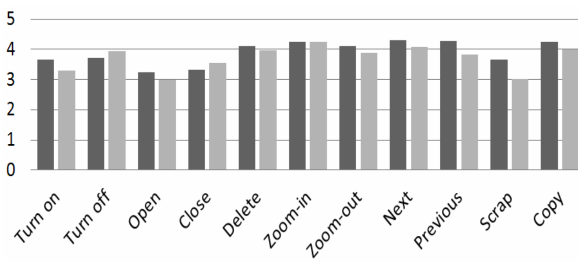

Figure 2 User preference for each command and device size. (■ small-sized; ■ large-sized)

$$A = \frac{\sum_{r \in R} \sum_{P_i \subseteq P_r} \left(\frac{|P_i|}{|P_r|} \right)^2}{|R|}$$

Figure 3
Calculating agreement score [12]. Where r is a referent (i.e. the command) in the set of all referents R, Pr is the set of proposed gestures for referent r, and Pi is a subset of identical gestures from Pr. When the agreement score is equal to 1, which means that all users performed same gesture for certain command, while as the score is close to 0, this means more different gestures were performed for one command.

observed during the study. The experiments contained two sessions for each participant. At each session, the participants were asked to articulate gestures for 11 commands that were randomly presented for one device. The sequence of the sessions was randomized. The reason we divided into two parts and assigned one size to each session was to minimize the possibility that a participant would retain a gesture for the same command from a previous size of device. After each session, we gave the users a break to help refresh their minds. Prior to the start of the experiment, we gave the participants a detailed introduction on the commands. We also asked the users not to think about how unique their gestures were, but to focus on devising the most natural and appropriate gesture for the given command. We tried to continue a conversation with the users, so that they could openly, verbally express their feelings or opinions about their actions. Once the participants came up with gestures for each command, they were asked to record their preferences for that gesture with 7-point Likert scale. The entire process of the experiment was video-recorded. The average time for one session was 13.1 minutes, and total elapsed time, including the introductory part and the breaks, was approximately an 30 minutes for each participant.

Results

Gesture Ratings. Immediately after performing each gesture, the users were asked to record their preference for that motion with 7-point Likert scale (0 as the least preferred and 6 as the most preferred). The *next* command with the *small-sized* device showed the highest average preference at 4.31, followed by *previous* and *zoom-in* commands with the same device. For the *large-sized* device, *zoom-in* command had the highest average preference at 4.25. The *open* command with the *large-sized* device showed the lowest at 3.00 (Figure 2).

Average preferences for each device size across all commands were 3.71 for the *large-sized* (SD=1.46), 4.01 for the *small-sized* device (SD=1.37). Statistically, the *small-sized* device showed a significantly high preference compared with the *large* one (t=-2.073, df=729, p=0.001). For *small-sized* device, preferences were higher than *large* device in all commands except *delete*, *turn off*, and *close* commands. Average preference for all gestures was positively recorded at 3.80 (SD=1.42).

Agreement. In order to understand the participants' consensus level towards a given gestures, we used the agreement score, which is applied in previous studies [5,12,13] to quantify the degree of agreement among the participants as a single number. This score is calculated with the formula as Figure 3.

Figure 4 shows the agreement score for each of the commands and device size. The *zoom-out* (0.540) with *small* device and *zoom-in* (0.357) with *large* device were the commands that showed the highest consensus levels, while the *open* command with *small* device was the lowest (0.100). Regarding the size of device, the agreement with the *large-sized* device (0.219) was higher than the *small-sized* device (0.209).

Patterns of Use. Most gestures were made as users clutched the device horizontally. Only 9.8% of the gestures with the *large-sized* device and 12.7% with the *small-sized* device were made as the device was held vertically. While all participants use their two hands for manipulating *large-sized* deformable device, 13.4% of

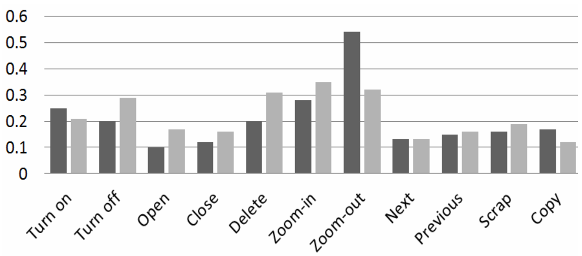

Figure 4 Agreement score for each command and device size.
(■ small-sized; ■ large-sized)

the gestures with the *small-sized* device were performed with only one hand. Interestingly, 75% of those one-hand deformable gestures were made with users' non-dominant hand. Gestures performed with one hand showed high preferences (4.31, SD=1.48) than gestures using two hands (3.95, SD=1.41).

Discussions

Our results show that the small-sized deformable device is preferred. The reason why users' ratings are higher for the small-sized device can be discussed from users' think-aloud and debriefing interview. For the *large-sized* device, some users (10 out of 36) mentioned about their preference of the touch interface. This implies that the touch interface should not necessarily be ruled out in designing deformable interfaces especially for *large-sized* display devices. For the *small-sized* device, however, no one expressed their desire to touch the screen. Also, while few participants (3 out of 36) expressed their fatigue for manipulating *large-sized* device due to the wide movement range, all users can manipulate *small-sized* device without physical efforts.

For the gestures that are created by users, more deformation based gestures are defined for the small-sized device. For the *small-sized* device, average of 9.36 (SD=2.24) unique gestures were defined by users for one command, while average of 7.46 (SD=1.67) unique gestures per command were defined for the *large-sized* device. As a result, the *small* device (0.209) has lower agreement score than *large* one (0.219), meaning that the participants' consensus level towards a certain gesture is low in the *small-sized* device. However, with the *small-sized* deformable device, users could choose gestures from larger deformation gesture pool and could select more preferable gestures (average preference is higher for the *small-sized* device). With the *large* device, most gestures consist of bending upward or downward while left-central and right-central part of device was grabbed with both hands. On the other hand, with the *small* device, various deformation gestures were used such as bend upward and downward repeatedly, or twist each corner delicately.

For the patterns of use, horizontal orientation is preferred in both sizes. We intentionally placed the device on the table in a diagonal position to let users select the orientation with their own preference. Although vertical use is increased in *small* device (12.7%) than *large* one (9.8%), most gestures were performed while the device was held in horizontally. It is interesting since the horizontal use is contrary to the conventional way of using both A4-sized paper (large size) and smartphone (small size). An interesting point is that one-hand deformation gestures with small device were resulted in high preferences Which is a notable finding since one-hand deformable interaction has not been studied in previous works, while many deformable interaction techniques were studied based on two-hand gestures [1,2,3,5,7,8,10,11]. One-hand deformable gestures were well matched with *zoom-in, zoom-out, previous*, and *next* commands. Another important finding here was that 75% of those one-hand deformable gestures were made with users' non-dominant hand. It means that users' dominant hand is free to interact in other methods such as touchscreen interface while non-dominant hand is supporting device and performing deformation based interaction.

Conclusion, Limitation and Future Work

The work studied how the device size affects the interaction design of deformable user interfaces. We compared two sizes of deformable user interfaces using mockups. This is the first time for trying to provide implications regarding device size on deformable user interfaces. We compared and discussed users' preferences toward two different sizes of deformable devices. We also covered user-defined gestures and patterns of use for each device size. As a preliminary study for understanding form factors for designing deformable user interfaces, this study clearly show that the device size is an important factor to consider when designing deformation based interaction.

As a limitation of this study, our paper mockup devices cannot give any real feedback. This low fidelity experiment will not give us all important implications. Also, the study has compared only two different device size, and there will be many factors may have an impact on the findings, such as device materials, display output and weight/thickness of the device. Therefore, our future works will cover those various spectrums of form factors with real feedback.

We hope that this study will be a starting point for understanding various form factors that influence and effect on how users interact with mobile devices that can be deformed.

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