Augmenting Bend Gestures with Pressure Zones on Flexible Displays

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Abstract
Flexible displays have paved the road for a new generation of interaction styles that allow users to bend and twist their devices. We hypothesize that bend gestures can be augmented with "hot-key" like pressure areas. This would allow single corner bends to have multiple functions. We created three pressure and bend interaction styles and compared them to bend-only gestures on two deformable prototypes. Users preferred the bend only prototype but still appreciated the pressure & bend prototype, particularly when it came to the lock/unlock application. We found that pressure interaction is a poor replacement for touch interaction, and present design suggestions to improve its performance.

Author Keywords
Deformable User Interface; Flexible Displays; Gestures; Mobile Device; Bimanual Interaction.

ACM Classification Keywords
H.5.2. Information interfaces and presentation: *User Interfaces – Interaction styles, user-centered design.*

Introduction
Flexible displays are an emergent technology that has inspired researchers to explore interaction techniques such as bending, twisting and crumpling [1] on

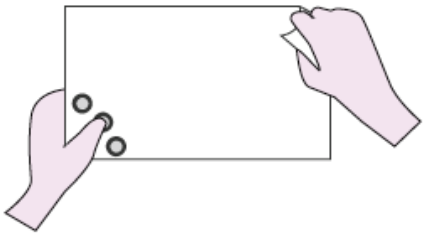

Figure 1. Press & Bend as Simultaneous Gestures

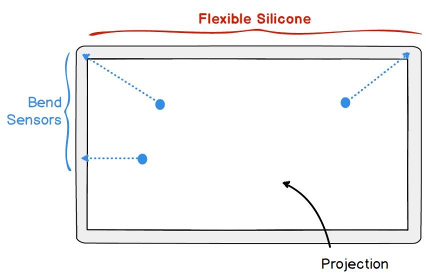

Figure 2. Bend Only Prototype

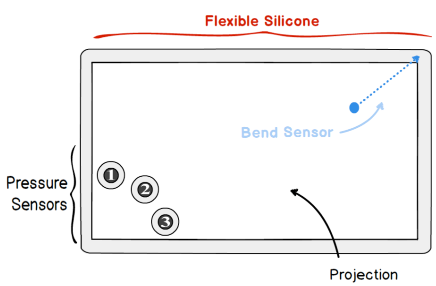

Figure 3. Bend and Pressure Prototype

multimedia devices [2,3]. We can use these gestures on a variety of applications, such as phones, music players, map navigation, e-readers [2,3].

As these applications become more complex, the number of bend gestures necessary for interaction will increase. Our research goal is to reduce the amount of bends a prototype might have to support while keeping the directionality and tangibility bend gestures provide. To achieve that, we leverage recent work that found that users can efficiently interact with the thumb of the holding hand on both rigid and flexible devices [6]. Hence, we propose that the behavior of one gesture can be modified by using three pressure zones (Figure 1). We suggest making these areas act like control keys on a keyboard, changing the behavior of a bend to match different application appropriate actions. We hypothesize that this would reduce the number of complex bend gestures the user would need to memorize. In this paper, we define new interaction styles for the press & bend prototype and compare them with the bend only gestures to determine user preference.

Related Work

We introduce bend gestures on flexible devices, before discussing pressure and touch input, and thumb interaction with touch rigid or deformable devices.

Bend Gestures on Flexible Devices

Kildal et al. discussed the development and testing of the Kinetic Device [2], a deformable user interface that focused on bending and twisting. Users found that bending to zoom and twisting to scroll to be intuitive gestures that required little learning. They also found that the gestures were more easily performed when holding the device with two hands.

PaperPhone is a flexible E Ink display that features bend gesture recognition [3]. Lahey et al. determined the effectiveness of several bend gestures through smartphone applications. They found that the directionality of actions appeared to be based on the participant's mental models. Their results also indicate that users preferred gestures that were conceptually simpler, and that they gravitated towards the different sides and corners of the display. Warren et al. [8] classified and determined which bend gestures users find the most friendly and intuitive. Their results showed a preference for the top corners and the sides. They recommended mapping frequently used functions to the top corners. The authors argued that bend gestures should be limited to two levels of magnitude; though note that this might be specific to their own prototype.

Thumb Interaction with Touch Devices

BiPad explores bimanual interaction on tablets and identifies five holds that permit simultaneous support and interaction [7]. Wagner et al.'s results suggest that participants significantly preferred bimanual taps (with the thumb) over other bimanual gestures. Riyadh explored tapping with the thumb of the holding hand on flexible tablets and found that users can efficiently interact with their thumb on both rigid and flexible devices [6]. He identifies a preference for holding the device on the center of the sides or the bottom corners (analogous with BiPad's findings). He also found that users can equally tap two or three regions for each hold. Riyadh suggests that future research explore how

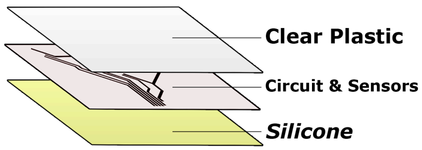

Figure 4. Exploded view of our prototypes

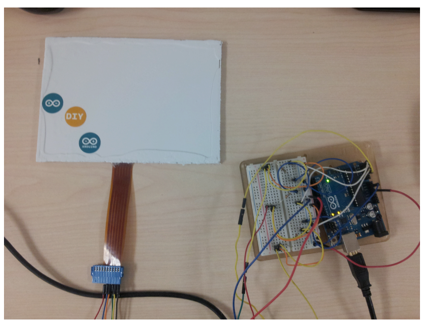

Figure 5. Bend & Pressure Prototype

the use of thumb gestures can complement bend gestures in bimanual simultaneous interactions.

McLachlan et al. demonstrated that pressure sensors can provide a useful augmentation to finger/stylus inputs on touch screens [5]. Their results suggest that users can apply, release and maintain pressure accurately when using their non-dominant hand while interacting with a touch-screen.

Prototypes

For this study, we created two flexible prototypes: bend only, pressure & bend. The bend only prototype (Figure 2) includes three bend sensors, placed on the top corners and on the left side. This placement is based both on Warren et al.'s suggested best bend locations [8], and to keep the right side interactions as similar as possible to the two prototypes.

Our second prototype (Figure 3) includes a single bend sensor located on the top right corner, and three pressure sensors located on the left bottom corner. This leverages Riyadh's findings in terms of hold position and touch targets [6]. We chose to use pressure sensors as a quick and inexpensive prototyping material, since flexible transparent touch sensors are currently difficult to find. The pressure sensors also allowed us to explore the possible benefits of using the amount of pressure as an input value. We placed static stickers to indicate their location to the user.

We built the two prototypes using a similar methodology as in Lo & Girouard [4]. Our prototypes consist of a thin film of clear plastic, a custom flexible printed circuit, and a layer of Alumilite Silicone Rubber (70A) (Figure 4). This creates a flexible, deformable prototype that naturally reverts to a flat state (Figure 5). We simulated the flexible display using a pico-projector.

Interactions Styles

We propose three interaction styles that combine bend and pressure gestures. We utilize the pressure sensors as a simulation of touch (low pressure/no pressure), and as a force input (amount of pressure exerted).

Pressure to change the behavior of bend gestures
One bend gesture is used to activate different functions according to the pressure sensor activated (at a low threshold). For example, in a physics game, applying pressure to a specific sensor while bending the right top corner up and down can raise or lower the intensity of an element (e.g. gravity, wind or air pressure). Each element would be associated with a different sensor.

Pressure to change the intensity of bend gestures
One bend gesture triggers the same action at different intensities, depending on the pressure sensor activated. For example, in a game, holding different sensors while bending can change the speed of player movement.

Varying pressure to change the behavior of bend gestures
One bend gesture triggers different actions depending on the force exerted on the pressure sensor(s). This may be particularly useful for actions that need user attention, such as unlocking/locking the device or confirming an action with significant consequences (e.g., reformatting the device, confirming credit card purchases).

Experimental Study

Our main goal was to evaluate and compare participant satisfaction between bend only and pressure & bend interactions. We ran a within-subject factorial experiment with two prototypes and three applications. Participants first interacted with the prototypes to familiarize themselves with the new interactions styles. We counterbalanced the order of the prototypes and the applications. Participants filled out a survey that recorded their impressions and comments.

Applications

We implemented three applications: lock/unlock, e-book reader and a music player. We selected them to represent typical applications a user might find on their mobile devices [2,3]., as well as implement all three interaction styles. Table 1 lists the different gestures for each action, on each prototype. The bend up/down actions were selected accordingly to the directionality of the action. We kept the bend directionality identical between prototypes.

LOCK AND UNLOCK

This application simulates a mobile device's lock screen. On the Bend & Pressure prototype, the bend is only activated if the user exerts more than a preset amount of pressure onto the sensor. Conversely, the Bend Only prototype requires two simultaneous bends for the device to lock or unlock.

ZOOM AND SCROLL

The zoom functionality allows users to zoom in and out of a small circle, simulating modifying the size of elements on their screen. The scroll functionality allows users to scroll up and down to read different sections of a short passage of text. On our bend only prototype, the size of the bends determines the speed of the action, whereas in our bend & pressure prototype, the speed is determined by the area pressed.

Action	Pressure + Bend Prototype	Bend Only Prototype
Lock	Strong press #2, Bend up	Both top corners bend up
Unlock	Strong press #2, Bend down	Both top corners bend down
Zoom/Scroll in at speed 1,2,3	Press #1,#2 or #3, Bend Up	Small/Medium/Large Left Corner bend Up
Zoom/Scroll out at speed 1,2,3	Press #1,#2,#3, Bend down	Small/medium/large left corner bend down
Play song	Left corner up	Left corner up
Pause song	Left corner down	Left corner down
Next song	Press #2, Bend down	Right corner down
Previous song	Press #2, Bend up	Right corner up
Lower Volume	Press #3, Bend down	Left side down
Raise Volume	Press #3, Bend up	Right side up
Browse Library	Press #1, Bend down/up	Both top corners l bend down/up

Table 1. Gesture Pairing for Each Action/Prototype

MUSIC PLAYER

The music player allows the user to listen to various songs. On our bend only prototype, we mapped functionalities to a different bend gesture. For the bend and pressure prototype, the action executed by the top-left bend is determined by the pressed zone.

Participants

Twelve participants (6 males) completed the hour long usability study and received $10 as compensation.

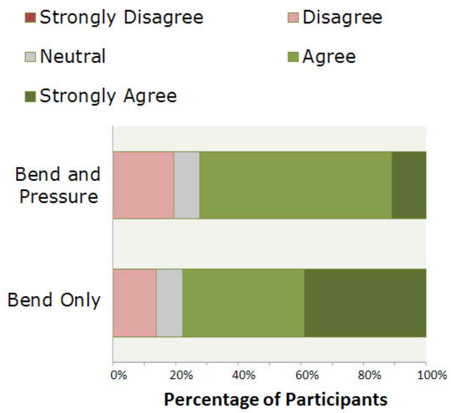

Figure 6. Average satisfaction level across applications.

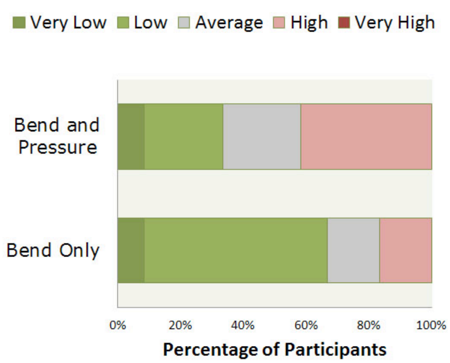

Figure 7. Frustration Levels

Results

Overall, 84% of participants preferred the "bend only" prototype, 16% preferred the "bend & pressure" prototype.

We invited participants to rate their satisfaction levels with each application on each prototype (Figure 6). 72% of participants agreed or strongly agreed to having enjoyed using the Bend + Pressure prototype, against 77% for the bend only prototype. Specifically, 84% participants agreed or strongly agreed to enjoying the lock/unlock prototype on both prototypes. Figure 7 compares the participants' frustration levels: 42% of users felt a high level of frustration (strongly agree) when using the bend & pressure prototype, versus 17% for the bend only prototype.

When asked which application the preferred using each prototype, participants scored the scroll up/down (specifically at speed 2) gesture the lowest: only 50% of participants preferred performing this gesture on the bend only prototype. In contrast, 84% of participants preferred the raise/lower volume on the bend only prototype (highest score).

Discussion

Our results show that users found the bend only prototype more enjoyable to use than the pressure and bend prototype. A large majority (84%) preferred the bend only prototype, but participants showed similar satisfaction levels (77% vs 72%). These results suggest the potential of our interaction styles.

The key difference between the two prototypes is the amount of physical actions needed to complete each task. Apart from the lock/unlock application, the bend only prototype required users to perform a single action (bend different areas of the device up or down), whereas the bend & pressure prototype required them to do two (apply pressure on an area, and bend up/down). These coupled actions took longer to complete and made users more prone to errors.

Additionally, participants seemed to regularly forget the functionality of the pressure zones. Only half of participants agreed that gestures were easy to remember on for the pressure & bend prototype, with 58% for the bend only prototype. Participants commented on how haptic and dynamic visual feedback (such as dynamic labeling of the buttons) would be an effective method of helping them remember the uses for each gesture/press.

Finally, we used pressure sensors to simulate touch due to prototyping constraints. However, the sensors only activated reliably when users squeezed the area instead of applying simple unidirectional pressure. This forced participants to locate the front and back areas of the sensors instead of simple touches on the surface. We observed that this negatively impacted their experience. Because of this, we believe that pressure sensors, specifically, force-sensing resistors, present a poor simulations of touch interactions. However, the results for lock/unlock application suggests that varying pressure can be a valid input source.

Design Recommendations

We formulate 3 recommendations based on our results. First, we suggest that pressure as a simulation of touch to augment a bend gesture be used only to replace complex bends, such as gestures that require bending multiple corners at once. Second, participants did not appreciate the pressing (squeezing) gestures as a simulation of touch. We recommend only using pressure sensors when there is a need for an extra dimension of input. Finally, when possible, provide appropriate dynamic visual feedback to all applications, such as labeling touch/pressure areas to make them easier to remember.

Limitations

Our prototypes were not optimal: there were loose areas, exposed circuits, air bubbles and weak adhesion that caused the bend and pressure sensors to output erratic values at different intervals. We also noted that bending away caused the pressure exerted on the pressure sensors to diminish, causing them to deactivate and cause erratic behavior. Interestingly, this gesture has caused "ergonomic challenges" on bend only devices [8]. Finally, we also only tested one level of flexibility, with one device size. Finally, while the simulation of display by projection is lightweight, participants observed distortion and occlusion when bending the device causing some frustration.

Conclusion

In this paper, we explored augmenting bend gestures with pressure areas to reduce the amount of bends a prototype might have to support. We introduced three new interaction styles and compared a bend & pressure and a bend only prototype to analyze user preferences and frustration levels. Furthermore, the pressure & bend prototype showed promise (72% enjoyed the applications). Because of this, we believe that exploring the combination of bend and touch gestures is still worth it. Future work includes augmenting pressures areas with resistive or capacitive touch areas to allow for reliable touch and pressure input. We also suggest exploring different sizes, and levels of thickness and flexibility to evaluate the influence of the form factor on the experience.

Acknowledgements

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