Bend Gesture Classification for Deformable Displays

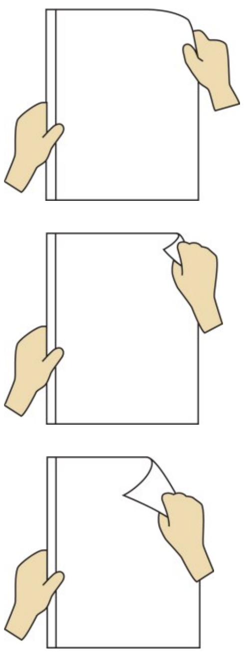

Figure 1. Collocated gestures, e.g. a small, medium and large angle bend, may be difficult for users to distinguish in practice.

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Abstract
Bend gestures have a large number of degrees of freedom and therefore offer a rich interaction language. We propose a classification scheme for bend gestures, and explore how users perform these gestures along four classification criterion: location, direction, size, and angle. The results suggest a strong agreement among participants for preferences of location and direction. Size and angle were difficult for users to differentiate. Finally, users performed and perceived two distinct levels of magnitude. We propose recommendations for designing bend gestures with Deformable displays.

Author Keywords
Deformable User Interface; Flexible Display; Affordance; Bend Gesture; Organic User Interface

ACM Classification Keywords
H.5.2 User Interfaces - Evaluation/methodology, Haptic I/O, Interaction Styles, Prototyping

Introduction
With the emergence of deformable displays, researchers are increasingly exploring the use of bend gestures as an input technique [2,3,5]. One of the main features of bend gestures is their large number of degrees of freedom: location, direction, size, angle, and speed, to name a few. Such variety offers a rich interaction language, yet can be overwhelming to

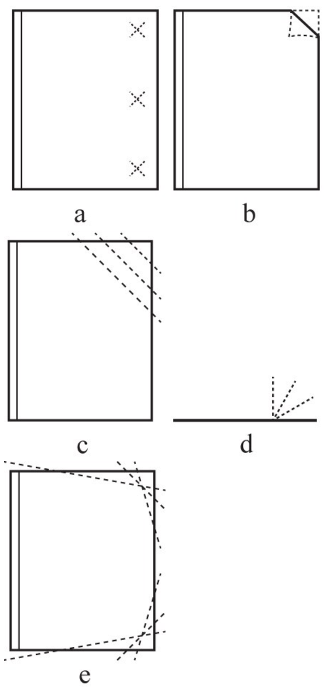

Figure 2. Classification of bend gestures: (a) location, (b) direction, (c) size, (d) angle, (e) edge. Size and Angle illustrate 3 magnitude levels.

users. When using PaperPhone, a flexible smartphone prototype, some users had trouble precisely repeating the same gesture, even given the use of limited bend classifications [2]. Bend gestures can be difficult to execute precisely, especially if users are required to distinguish between collocated gestures (Figure 1). Therefore, it is paramount to determine how users perform bends to create and implement appropriate bend gestures.

In this paper, we propose an extended bend gesture classification scheme. We also report the finding of a study where we evaluated how users naturally perform bend gestures with minimal instruction, and discuss design recommendations [4].

Related Work

We based our bend classification scheme on prior work that shaped the domain of deformable displays, a nice example of Organic User Interface [6]. Among the pivotal work, we find Gummi [5], PaperPhone [2], the Kinetic Device [1] and the work of Lee et al. [3].

Pioneering the flexible display research field, Schwesig et al. [5] created Gummi, a compact, flexible mobile computing system using bend gestures as input. Users navigated the content by bending a flexible extended besize of the rigid display. PaperPhone was the first prototype to use a fully functional flexible display [2]. With this smartphone prototype, Lahey et al. asked participants to define bend gestures, and associate those gestures with functionalities. They proposed a classification scheme that categorized bend gestures by location (top corner, side, or bottom corner) and their polarity (up or down). More recently, Nokia presented the Kinetic device, a deformable mobile phone which has rubber-like properties. Using this device, Kildal et al. [1] explored bending and twisting, and proposed a set of design guidelines with deformable devices, such as the appropriateness of discrete bend gestures to trigger discrete functionality. Finally, Lee et al. [3] generated a set of interaction gestures for deformable displays. The participants were instructed to deform displays to execute specific tasks. Their results included a number of bend gestures, such as bending upwards, downwards; bending the middle, the side or the upper corner of the artificial display.

Bend Gesture Classification Scheme

Bend gestures can have a variety of complexities: they can be defined according to a simple classification scheme composed of location and polarity of the force, such as in PaperPhone [2], but their large number of degrees of freedom suggests more complex gestures can be implemented. We build on PaperPhone's initial bend gesture definition to create a classification of bend gestures. Figure 2 illustrates five characteristics. We work with design constraints of current flexible displays, which contain a rigid bezel, but we believe our classification can be extended to devices without rigid elements.

- **Location**: Where the bend takes place on the device: e.g. top corner, side, bottom corner.
- **Direction**: The direction of the bend: upwards (toward the user), or downwards (away from the user). This was referred to as polarity in PaperPhone.
- **Size of the Bent Area**: The bent surface area of the device, e.g. 1/5th of the device bends.
- **Angle**: The degree of perpendicularity of the bend in relation to the device plane. These bends can be spoken of in terms of angle in relation to the plane.

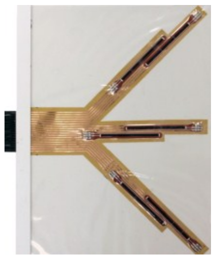

Figure 3. Left: the bend sensors layout at the back of the prototype. Right: the prototype used in the study.

- **Edge**: A bend performed by holding an edge of the device.
- **Speed of Bend**: The time taken to move the device from the neutral position to the bend position.
- **Duration of Bend**: The length of time the bend is held in place before returning to neutral position.

To design this scheme, we performed a pilot study where we observed users bend pieces of paper. We saw users naturally performing gestures based on location and direction (also found by Lee [3] and Lahey [2]). The next most common variables were size and angle. We find that our classification yields a hierarchy of importance: one must first classify a bend by location and direction, then by size and/or angle, before discussing speed and duration of bend. Using this hierarchy, we created a succinct study concentrating on the higher level descriptors of natural bend gestures: location, direction, size and angle.

Exploring Bend Gestures Study

While computers may be able to recognize even the smallest movement in a bend sensor, human abilities are not as precise. Our goal was to determine how many degrees of freedom individuals can consistently differentiate within the classifications chosen. Results and analysis are available in our CHI 2013 paper [4].

We created a letter size, flexible prototype to detect the location, direction, size, and angle of bends (Figure 3). We used six bidirectional bend sensors, placed in pairs at three locations. Each pair allowed us to between size and angle. We partially overlapped them to create three zones per pair. We determined the *size* of the bend by observing which bend sensors are activated (the inner sensor, both sensors, or the outer sensor). We correlate the sensor values to obtain *angle*.

Participants were 13 university students and employees. They were asked to perform a series of bend gestures with minimal instruction. They were given a magnitude (small, medium or large), a characteristic (angle or size), a direction (up or down), and a location (top corner, side, bottom corner). Participants were directed to perform the bend gestures naturally. They performed 36 unique bends during each of three trials for a total of 108 bends per participant. At the end of the study, a semi-structured interview was conducted to measure user preferences.

Discussion

Participants showed strong agreement on bend gesture preferences. Participants performed smaller bends downward than upward. We also found that many users indicated bending downward to be more awkward than upwards. Participants performed the largest bends in the top corner location, followed by side. This may be due to the ease of bending in the top corner and side locations reported by participants.

Users showed a preference for the top location, followed closely by the side location. This preferred location corresponds to that of previous work [2,3]. The overall preferred gesture, the top corner upwards, differs from that noted in PaperPhone, i.e. the side location [4]. Users found the bottom corner bends most difficult to perform. Participant observations revealed an ergonomic explanation for this trend, as most participants attempted several hand positions in the bottom corner location before settling on the most comfortable to perform the bend. This suggests the bottom corner to be the least ergonomic. Finally, small angle and size bends are preferred over medium or large, being more ergonomic and providing the least amount of screen occlusion.

In general, we observed a disconnect between the user perception of accurate bends performed and their actual performance. For instance, we hypothesized that users would have difficulty differentiating between three levels of magnitude, and our results both support and counter the hypothesis. While the statistical analysis supported the use of three levels of magnitude, this result is not meaningful once we observe the zones activated, and how users performed bends. In short, our participants typically performed small and medium size bends at a sharp angle, activating the sensors as predicted, while their large size bends were quite curved, which activated the sensors similarly to a medium bend. Hence our current prototype cannot reliably detect large bends. In addition, many users indicated a preference for two magnitudes rather than three for both size and angle.

Design Recommendations

When designing bend gestures, the function and complexity of the application should be taken into careful consideration. We formulate general design recommendations from our classification and study:

- **Map frequently used functions to the top corner**: The top corner was the most preferred location followed by side and then bottom corner. We recommend mapping frequently used functions the top corner to optimize usability.
- **Use two levels of magnitude**: We recommend two levels of magnitude to increase the distinction between bend gestures for deformable devices with similar physical attributes to our prototype. Our participants reported confusion relating to three levels of magnitude, and a strong preference for two.
- **Select either size or angle**: The distinction between concepts of size and angle was often unclear to users, based on how users performed bend gestures, as well as their interview comments. For instance, several users described bends using the term "curvature", which is a combination of size and angle. If one needs to describe a gesture precisely, we recommend selecting either size or angle.
- **Create an adaptable classification algorithm**: We suggest developing classification algorithms that take into account the significant variability observed in the magnitude of bends for each location and direction.

Acknowledgements

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