Snaplet: Using Body Shape to Inform Function in Mobile Flexible Display Devices

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CHI 2011, May 7–12, 2011, Vancouver, BC, Canada.
ACM 978-1-4503-0268-5/11/05.

Abstract
With recent advances in flexible displays, computer displays are no longer restricted to flat, rigid form factors. In this paper, we propose that the physical form of a flexible display, depending on the way it is held or worn, can help shape its current functionality. We propose Snaplet, a wearable flexible E Ink display augmented with sensors that allow the shape of the display to be detected. Snaplet is a paper computer in the form of a bracelet. When in a convex shape on the wrist, Snaplet functions as a watch and media player. When held flat in the hand it is a PDA with notepad functionality. When held in a concave shape Snaplet functions as a phone. Calls are dropped by returning its shape to a flat or convex shape.

Keywords
Flexible Displays, E Ink, Bend Gestures, Organic User Interfaces

ACM Classification Keywords
H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

Introduction
Mobile devices are electronic chameleons, changing from phones to notebooks to maps to media players at

Figure 1. Snaplet, when worn in a convex shape as a wristband, switches its application context to watch and media player functionality.

Figure 2. Snaplet held flat changes to a PDA with pen-based note taking functionality.

the whim of the user. They are no longer static single function tools, but are instead powerful general-purpose computers with increasingly sophisticated sensors and communication systems connecting them to the world.

As is typical with multi-function tools, sacrifices in individual application performance are traded for versatility. Moreover, the ergonomic relationship of the phone to the user's body is diminished in quality by the requirement to have a flat display. The screen real estate is less than would be ideal for viewing media because the device must fit in the user's pocket.

Interaction modalities with mobile devices have evolved with their functionality. When mobile phones were only phones, interactions were extremely limited in duration and complexity and conformed to the familiar rules of their wired progenitors. With new functions came new buttons, GUI's, touch screens, and a whole range of other sensors. Interactions are now much more prolonged and diverse in nature. They are now frequent enough that people will take their mobile devices out of their pockets before sitting down at a table or getting in a car rather than only getting out the device when actively planning to use it. This tendency to always have the device at the ready highlights the value of wearable technology but the diversity of ways in which these devices are used argues for hardware that can be manipulated with one hand, bi-manually as well as shared with others.

We propose that an emerging class of mobile computing devices, flexible computers, will address many of the above problems with current hardware. These flexible devices will be lightweight and will not have the rigid bodies and glass screens that can break when dropped. They can conform to shape of the user's body, enhancing the ergonomic relationship, yet be flat when that form is called for. Their flexible nature facilitates comfortable and fashionable wearable designs. While the concept of bendable computers has been discussed before [3, 5, 9], the implementation of such a computer has been delayed by technical difficulties [5]. With recent advances in flexible electronic paper display, output devices are no longer restricted to a flat form, and we have the opportunity to create functional flexible prototypes.

In this paper, we present a first example in this new category of flexible display devices called Snaplet. Snaplet is the prototype of a flexible computer and interaction paradigm based on a flexible electronic paper display (Figure 1). This mobile computer can be worn on the wrist, allowing hands-free viewing or one handed interactions, or can be snapped off and held in the hand during phone calls or for (bi-manual) focus tasks. Snaplet takes advantage of the affordance provided by the flexibility of the device to produce a new interaction paradigm: the shape of the user's body determines the shape of the device, and accordingly, its current function. Our Snaplet prototype demonstrates how the way the user holds a flexible device can lead to the alteration of its physical form, which in turn can alter its functionality.

Snaplet uses bend sensors to classify the shape of the device. This information drives a state machine, which determines which applications to run and what commands to perform based on the calculated context of use. Snaplet uses pressure sensors to detect screen touch. Finally, Snaplet uses a Wacom flexible tablet to allow stylus interaction.

Prior Work

We will limit our discussion of prior work to a few systems that inspired the design of Snaplet.

Schwesig et al. [9] pioneered the idea of a bendable computer, and presented Gummi, a functioning prototype that integrated one-dimensional bends to control 2D position in maps. They augmented a flat rigid display with flexible plexiglass, and their interaction included both states of complete bending, or transitional bends.

PaperWindows was a prototyping environment that implemented flexible displays by projecting digital windows on paper [3]. The system tracked the position and curve of the paper using a Vicon motion capture system and adapted the projected image accordingly, allowing users to interact with multiple simulated flexible displays.

Lee et al. [5] argued that previous work in deformation-based interfaces was limited by many technological challenges. They bypassed these limitations by asking users to generate gestures for a variety of tasks, using three different materials (paper, plastic and cloth). However, none of these interactions were programmed or implemented to test their efficacy in a functional system.

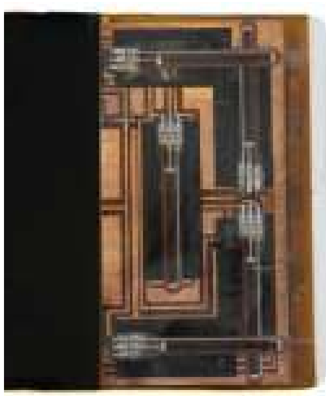

Figure 3. The back of Snaplet, showing the FPC with an array of bend sensors under a transparent laminate.

The relationship between mobile devices and body parts was also explored by Guerreiro et al. [2] who created mnemonic body shortcuts based on the association between applications and the body space. Using their prototype, users could activate the clock by tapping the phone on wrist, or start the photo application by placing the device close to their eyes.

With Graspables, Taylor and Bove [10] argued that user associate devices with the way they hold them. They presented SoapBar, a device that changes context by sensing how it's held. SoapBar can be used as a phone if held with one hand at an angle, or as a camera when held with two pinches.

Snaplet

Snaplet was designed for three wearable application contexts: a watch context (Figure 1), a PDA context (Figure 2) and a mobile phone context. Each context is associated with a limited number of mobile application functions. To use Snaplet as a watch, the user places the flexible screen along the curvature of their wrist, horizontally, bending it upwards. The user affixes the curved display on a shirt using Velcro. In this context, the user can watch a video, or play with a music application. To use it as a PDA, the user removes the device from the wrist, and holds it flat inside the palm of the (non-dominant) hand. Users can use their dominant hand to interact with the display using a stylus, or using deformation of the display. In this context, the user can read a book, take notes or sketch on the display. Users can pick up a phone call by bending the edge of the display with their fingers, then placing the device to their ear.

Apparatus

Snaplet consists of an Arizona State University Flexible Display Center 3.7" Bloodhound flexible electrophoretic display [7], augmented with a layer of 5 Flexpoint 2" bi-directional bend sensors and 6 pressure sensors. The prototype is driven by an E Ink [1] Broadsheet AM300 Kit featuring a Gumstix processor.

An Arduino Mega microcontroller obtains data from the Flexpoint bend sensors and pressure sensors. Figure 3 shows the back of the display, with the bend sensor configuration mounted on a flexible printed circuit (FPC) of our own design. We built the FPC by printing its design on DuPont Pyralux flexible circuit material with a Xerox Phasor solid ink printer, then etching the result to obtain a fully functional flexible circuit substrate (Figure 3). Sandwiched behind this bend sensing layer is a flexible Wacom pen interface. This allows Snaplet to sense the coordinates of a Wacom pen touching the display.

The AM300 and Arduino are connected to a laptop running a Max 5 patch that processes sensor data, performs gesture recognition and sends images to the display. Pen tracking is fully embedded on the AM300.

Automated Wearable Application Context Detection

Wearable application contexts are distinguished automatically by the system through recognizing the shape of the display. Snaplet uses a k-Nearest-Neighbor (kNN) algorithm with k=1 to recognize bend gestures. kNN assigns the label of the most similar examples (the closest neighbor) to the example to classify. In our case, the examples are vectors from the live values of the 5 bend sensors. This recognition algorithm requires only a single training input for each gesture, making it ideal for rapid programming of user defined bend gestures. A bend gesture is recognized when the display is bent to a curvature that is closer to a recorded shape than a flat shape.

Although Snaplet is fully flexible, the current design contains a number of fragile connectors on the left side of the display that may be damaged while bending. The right side of the display allows bends up to 45 degrees. Our bend gesture recognition system requires a minimum bend of 10 degrees for proper detection of bends.

Flexible Interaction Techniques

We propose two dimensions of deformations that guide flexible interaction techniques. First, we classify gestures using their immediacy, where we find static and dynamic actions. Second, we classify according to the deformation of the display, afforded by the body part where the screen currently is located (e.g. wrist, palm). We also implemented pen and touch input to further enrich the interaction experience of Snaplet.

Static Bends Provide Context

The most basic input in Snaplet is the static bend shape. The shape (or, rather, bend) of the display surface along the vertical (portrait) axis determines the wearable application context of the device. A convex shape allows Snaplet to function as a watch, a flat shape allows it to be used as a pen-based PDA, and a concave shape takes the phone off-hook. These shapes conform to the shape of the body in various wearable contexts: respectively, wrist, flat hand and grasping hand, thus producing distinct functional affordances [5].

Static bends offer visual and tangible cues of the current wearable context and application mode of the device, essentially allowing the user to make high-level menu or application selection. For instance, holding the phone in a concave shape requires a force, which

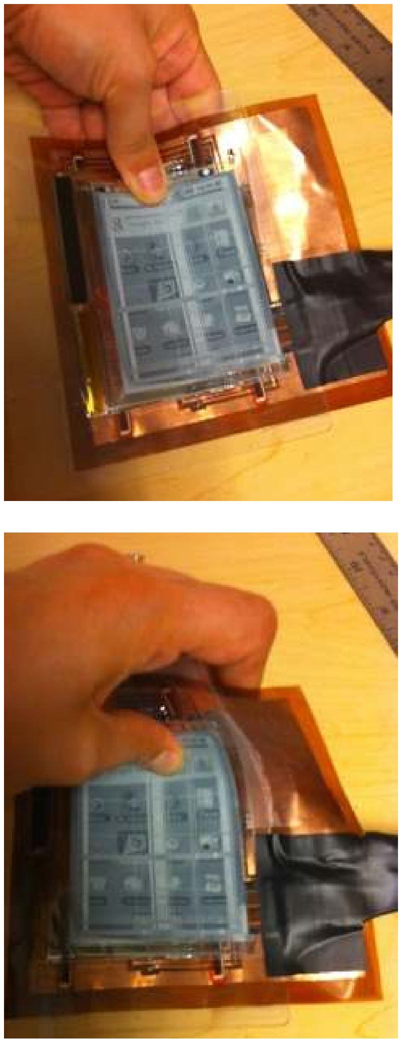

Figure 4. Example of bending a side (top) or a corner (bottom)

provides haptic feedback that signifies an ongoing call. Releasing the haptic energy directly corresponds to dropping the call.

Bend Gestures Trigger Actions
Our second category of actions consists of active bend gestures, which provide function within a wearable application context. Bend gestures allow the user to interact with specific applications, or change application in a given context. These actions are mostly metaphor inspired rather than designed around the body shape, and the action produces an immediate, visible result, such as pulling down a menu, scrolling or paging forward.

To avoid cross-talk with the static bends, bend gestures in this category are limited to deforming corners on one side of the display (Figure 4). Bend gestures are used in the PDA context, as they are impractical in both wrist and phone contexts. Given the current physical constraints of the display, there are only a few possible bend gestures: bending the top right corner, upwards or downwards, and bending the bottom right corner, upwards or downwards [4]. A combination of those four corner bends is also possible, for instance by lifting both corners up.

Pen/Touch Interaction
To enrich the interaction styles of Snaplet, the user can use touch interaction (through pressure sensors) as well as with the stylus. Pen interaction allows coordinate pointing and richer input such as sketching or taking notes. Touch interaction is the input source for icon navigation and menu selection.

In all, Snaplet offers varied input: bend, pen and touch. The simultaneous combination of inputs may also produce a wealthier interaction language by providing contextualized actions. For instance, in the context of note taking, the combination of bend and pen at once could allow access to select/cut/copy/paste actions. The user could bend the top corner up to start selecting text, releasing the corner to stop selection. The user could use the bottom corner to indicate whether to cut or copy, respectively by bending the corner up or down. Finally, the user could paste the text at the location indicated by the pen by bending the top corner downwards.

Discussion
We believe the Snaplet prototype is the first functional example of a flexible E Ink display that incorporates bend, pen and touch input for application context sensing. Snaplet demonstrates how the form of such devices can naturally follow that of the body throughout different interactions. Not only does this improve ergonomic aspects of the device, providing a comfortable fit to the hands and wrist, it also provides direct affordances that associate shape with the function of the device.

A third advantage of this particular use of a flexible display is its haptic qualities: forces exerted when performing bend gestures, whether static or dynamical, inform the body of the current functionality of the device. This means that, similar to stick shifts in cars, users can utilize the shape of the device for eye-free context switching, relying on haptic rather than visual feedback to determine the current state of the device [6].

We should note that due to the state of technology, the current design of Snaplet has some, hopefully temporary, drawbacks. We designed Snaplet as a wireless 4” display. However, the display and sensors require a cable bundle that interferes with a comfortable one handed grasp of the display. Also, the fragile display connectors require one side of the display to remain rigid, thus limiting the flexibility of Snaplet. In addition, gesture designers must be aware that holding patterns and static device shapes restrict the number of available dynamical gestures. An investigation of how people hold mobile devices, such as PDAs, may further aid in designing around these issues. When designing deformation-based gestures, attention seeking movements and physically uncomfortable gestures should be avoided, as they may influence the adaption of the technology [8].

For ergonomic fit, Snaplet should follow the body’s shape. However, in some cases, there is more than one body shape the device could follow. For instance, when in a phone call, the device could mold to the curvature of hand or the face. We selected to follow the curvature of the hand as the user needs a comfortable grip to talk.

Conclusions

In this paper, we discussed Snaplet, a wrist-mounted flexible E Ink display augmented with sensors that sense the shape of the display. When in a convex shape on the wrist, Snaplet functions as a watch and media player. When held flat in the hand it is a PDA with notepad functionality. When held in a concave shape Snaplet functions as a phone.

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