Towards Interaction with Transparent and Flexible Displays

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CHI 2013 Workshop on Displays Take New Shape: An Agenda for Interactive Surfaces, April 28, 2013, Paris, France.

Abstract
Prototypes for both flexible and transparent displays have been presented separately. Soon combinations of both aspects will be introduced, leading to new designs for mobile devices. We present possible form factors and an overview of the interaction vocabulary for such devices, including several concepts for novel interaction techniques.

Author Keywords
Mobile devices; transparent and flexible interfaces; interaction techniques

ACM Classification Keywords
H.5.2. User Interfaces: Input devices and strategies.

Introduction
While there has been research on interaction with flexible displays and, to a lesser extent, on transparent devices, there are little to none publications about the effect of combining both flexibility and transparency in one device. However, we firmly believe that mobile devices with screens combining these two aspects will be widely available in a few years.

In this position paper we propose possible form factors and an overview of the interaction vocabulary for such

Figure 1. Non-interactive mockup, utilizing back-projection onto a transparent foil.

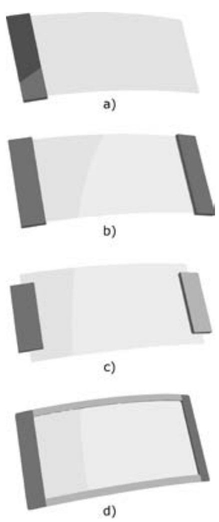

Figure 2. Different form factors of handheld, transparent flexible displays. *Single handle* (a), *Dual handle* (b), *Flexible corners* (c), *Complete Frame* (d)

devices, including several concepts for novel interaction techniques.

Related Work

Schwesig et al. [8] presented a prototype for small bendable computers. The conceived input modalities are back device touch input and up- and downwards bending of the whole device. Other, similar prototypes include PaperPhone [5], presenting various bend gestures for flexible E-Ink displays; BendFlip [11], focusing on an evaluation of input techniques for e-book readers; and Bookisheet [9], where the authors employ metaphors of turning pages. In DisplayStacks [1], Girouard et al. discussed interaction techniques based on stacking thin, flexible displays. Besides these bendable prototypes, other forms of flexibility have been proposed, like rollable [4] and foldable [3] interfaces.

A transparent display supporting touch input on both front and rear, LimpiDual Touch, has been used by Ohtani et al. [6] to test the effect of back device and dual-sided touch interaction versus frontal input. They found that, though reaction times are fastest for the front condition, users gain accuracy by seeing their fingers on the back of the screen. Earlier, back device interaction has been examined on pseudo-transparent devices in 2007's Lucid Touch [10] by Wigdor et al. Another approach to see-through displays, given that transparent screens are not yet commercially available, are projective setups using transparent mirrors. HoloDesk [2] by Hilliges et al. uses such a device for 3D interaction in a situated AR setting.

Form Factors

Although transparent circuitry already leads the way toward see-through displays, several other hardware parts (e.g., batteries) will not be fully transparent, at least in the foreseeable future. Therefore, while the notion of a completely transparent computer is compelling, we propose the following form factors for partially-transparent, flexible mobile devices that can be distinguished by the spatial configuration of the non-transparent parts (Figure 2). We differentiate between devices with one rigid part (single handle) and those with two (dual handle).

Single handle

These devices have one rigid part. They are usually held in the non-dominant hand and mainly manipulated with the other one (Figure 2a). We envision them to be not much bigger than today's larger smartphones or small tablets.

Dual handle

Devices with two rigid handles as in [4] are, obviously, normally held in both hands, limiting the flexibility (Figure 2b). We propose that such devices, for example used similar to tablets, could still have flexible corners to allow for a richer set of interaction techniques (Figure 2c). They could even have a complete frame with rigid handles and flexible parts for the longer, horizontal sides (Figure 2d).

Interaction Vocabulary

Based on a non-functional mockup (Figure 1) of one of the form factors described above, we compiled an overview of possible interaction techniques for transparent, flexible devices. We identify the following categories.

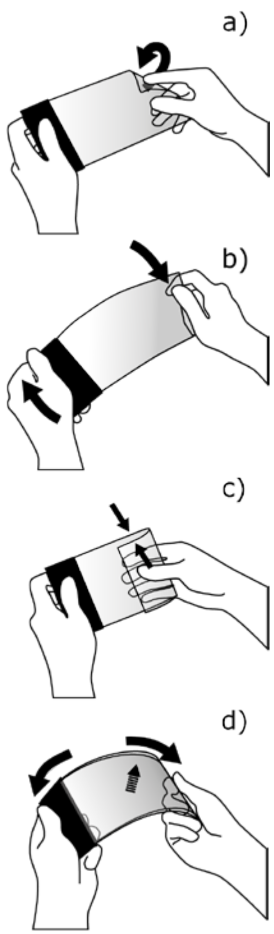

Figure 3. Some bending techniques: *Corner Bending* (a), *Twisting* (b), *Bend-Squeeze* (c) and *Stack and Bend* (d)

Bending

Bending is the main input modality arising from flexible form factors and has already been examined for non-transparent devices, e.g., in [5, 8, 9, 11]. Besides bending of the whole device, users can also bend either individual corners or one complete edge of the device [5]. Also, twisting (bending of opposite edges in opposite directions) is possible (Figure 3a, b).

The bending techniques presented so far do all apply for opaque displays. However, the transparency can be leveraged in bending as well. One possibility to do so is what we call *"Bend-Squeeze"*. Here, a flexible side of the device is bent around, creating an overlapped area that can be squeezed for pressure-based input (Figure 3c). Additionally, making use of the transparency, contextual information like a scale or a menu can be shown on this bent part, overlaying the actual content.

Multitouch and Pen Input

Flexible, transparent displays can be built to support both multitouch and pen input, even including pressure sensitivity [7]. Back device interaction is also specially supported by the transparency, giving users direct spatial feedback on their finger's positions while simultaneously allowing an unobstructed view on the displayed content.

Stacking

Another possibility to leverage transparency in flexible displays is to support *stacking* [1]. Use cases for this are twofold: On one hand, multiple stacked displays provide the means to overlay information, for example in combining different domain-specific views or public with personal views.
On the other hand, we propose *"Stack and Bend"* as an example for concrete interaction techniques: Two devices are placed on top of each other and are bent to initiate data flow between both, e.g., to copy files from one personal device to the other. The bending direction defines source and target of the flow (Figure 3d).

On-Object Interaction

Transparent and flexible screens lend themselves to interaction directly on objects and surfaces. As an optical see-through system they can blend digital objects and the underlying physical world. At the same time, their flexible form makes them useable even on curved surfaces such as car wings or pillars, augmenting those surfaces similar to, e.g., a label around a bottle. This important characteristic means that flexibility is not only an input modality but has also "passive" usefulness.

Besides showing graphical overlays of colors or textures, one particular goal may be to either access data connected to physical objects on a mobile device or store new information. Supporting this idea, we propose that the user can place the device on the surface/object and pick up or unload data to/from the device, e.g., by performing a swiping gesture on the display.

Applications

Although transparent, flexible devices can in principal be used for nearly all the same tasks as traditional mobile devices, there are several use cases that benefit especially from them.

Prototyping/Design Studies

Transparent, flexible devices can be used to showcase different colors, textures or even small design elements directly on physical prototypes and models. Compared to projector setups they are more portable and provide interaction capabilities on the augmentation. Their flexibility facilitates the application on bent surfaces, allowing for a more direct contact between object and augmentation.

Personally Augmented Collaborative Environments
In co-located, collaborative environments such as multi-touch tabletops, transparent devices may be used to augment the publicly presented information with user specific content. These personal views would still allow the view onto the whole scene and support peripheral awareness.

Conclusion

We have presented both an overview of form factors and several novel ideas for interacting with flexible, transparent devices. We think that there is a lot of potential for leveraging such devices' unique capabilities for interaction purposes. Various open research questions remain. Among them, how precise is (back device) touch input on flexible surfaces? How can the cognitive load resulting from transparency be reduced? How can prototypes already be constructed while real, flexible transparent screens are not yet available? And is the combination of transparency and flexibility really more useful than its parts?

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