

Towards More Paper-like Input: Flexible Input Devices for Foldable Interaction Styles

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ABSTRACT

This paper presents Foldable User Interfaces (FUI), a combination of a 3D GUI with windows imbued with the physics of paper, and Foldable Input Devices (FIDs). FIDs are sheets of paper that allow realistic transformations of graphical sheets in the FUI. Foldable input devices are made out of construction paper augmented with IR reflectors, and tracked by computer vision. Window sheets can be picked up and flexed with simple movements and deformations of the FID. FIDs allow a diverse lexicon of one-handed and two-handed interaction techniques, including folding, bending, flipping and stacking. We show how these can be used to ease the creation of simple 3D models, but also for tasks such as page navigation.

ACM Classification:

H5.2 [Information interfaces and presentation]: User Interfaces. – Graphical user interfaces.

General Terms:

Design, Algorithms, Human Factors

INTRODUCTION

With the prospect of new display technologies that mimic some of the physical properties of paper, such as e-ink [8] and rollable display technologies by Polymer Vision [10] and Sony [14], and Lumalive e-textiles by Philips [3], comes a renewed interest in designing computer input in a way that mimics the properties of flexible surfaces. Today's input devices do not utilize many of the possible degrees of freedom allowed by some simple everyday materials, such as paper and textiles [1]. Designers like tailors and architects make use of the deformability of such materials in the construction of their models.

Deformability is one of those desirable properties that affect the ease of use in many mundane tasks, like

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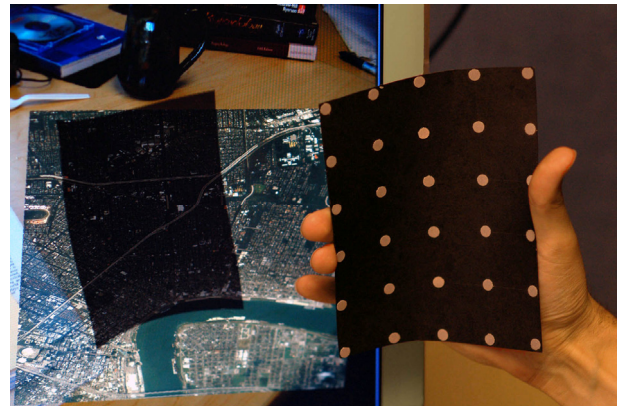


Figure 1. The Foldable Input Device's shape is mirrored in the Foldable User Interface's Transparency cursor.

reading. For example, the physical page flip is a wonderfully effective metaphor for navigating documents. While it has been mimicked [1], development of three-dimensional input devices that use surface deformation as a primary source of input has proven cumbersome. The reason for this is that it is difficult to sense surface deformations in a consistent, cheap and accurate fashion [15].

In this paper, we present Foldable User Interfaces: a cheap method for prototyping flexible display interactions using only a simple IR web cam and an LCD screen. Our Foldable User Interface (FUI), shown in Figure 1, simulates flexible displays in 3D graphical windows that behave according to the physics of real sheets of paper. Sheets can be folded, stacked, and even tossed onto a desktop. Our design included Foldable Input Devices (FID), pieces of cardboard that allow users to manipulate the shape and behavior of Sheets in 3D. An FID looks and behaves more like a mouse pad than like a mouse (see Fig. 1). They consist of cheap 5"x6" sheets of cardstock paper augmented with IR retro-reflectors, the shape and position of which is tracked through an IR web cam. FIDs funnel the tactile sensations of real materials into a highly flexible input device. We see FUIs as a natural exploration of paper-like display metaphors such as Paperwindows [4] and Gummi [12]. These systems either

require motion capture devices that are prohibitively expensive, or one-off hardware prototypes unavailable to the average user. The main benefit of this contribution then, is that it allows the exploration of foldable interaction styles on the cheap, at a cost easily afforded by the average user. We also discuss some new interaction styles made possible by the precision of FID shape detection. These include the use of marker occlusion, corner bends, hovering, folding, leafing and shaking gestures.

ORIGAMI AS A METAPHOR FOR INPUT

An important source of inspiration for our work was the old art of Origami [7]. Constructing things out of paper is simple, fun, cheap and surprisingly robust. Origami exercises exemplify how physical properties of sheets of paper might be leveraged for use as input. Figure 2 shows some basic deformations of paper that can be used as input. Paper can fold — a primary source of input for the construction of models — but it can also bend, often applied for navigation as it naturally uncovers a subsequent sheet. Pages can be bookmarked for future reference using earmarks, and spread, for example, to sort a stack of cards. However, paper also supports containment of other objects, for example, by scooping things into or shaking things out of a folder or paper bag.

The wonders of paper were also extolled in the work of Sellen and Harper [13], who studied why paper documents are still so widely in use in office environments. They proposed a set of design principles for incorporating properties of paper documents into the design of digital (input) devices. According to them, paper makes navigation tasks more flexible because input is direct, two-handed, and provides a rich set of non-visual cues. Paper also supports better cross-document use. Paper affords easier transitions between multiple documents by allowing users to pick up and organize two-handedly more than one document at a time. Paper is flexible, can be randomly arranged, annotated directly, and stacked. In our paper-based FID designs, we tried to leverage as many of these properties as possible to provide the user with a more direct way to manipulate window content. When designing FUI interaction techniques, we made sure that knowledge of paper interactions would easily be transferred to the digital domain, allowing users to rely on their past experiences with paper to carry out the tasks in our Foldable User Interface.

RELATED WORK

There is an extensive body of research in the area of paper interfaces [2,5,6,9,11,16]. Also, because FUI windows are not made out of paper, we refer to Holman *et al.* for an overview of that work [4].

FID HARDWARE OVERVIEW

The Foldable input devices are made of real sheets of black cardstock augmented with 25-35 infrared reflective reflectors made out of 3M retroreflective tape. The FID tracking system relies on a simple webcam, modified to operate in the near-infrared by removing the standard filter, and adding a ring of infrared LEDs around the lens. The use of infrared light allows greater robustness in tracking, and easier subtraction of background artifacts. An iMac running Windows XP is used to process the images of the camera in real time, using OpenCV. This computer also runs the OpenGL models, embedded in a C++ program, allowing real-time deformations and movements of the input devices to be detected and displayed in the Foldable UI.

FID INTERACTION TECHNIQUES

The foldable input devices are manipulated with the user's hands, and are used in combination with arm movements to create many different interaction techniques. Each technique is based upon a common way in which paper can be handled.

Allowing the use of multiple FIDs simultaneously gives us the ability to work two-handedly and with multiple Sheets. Two-handed techniques are also available when using a single FID. One of the key benefits of the ability to organize and manipulate Sheets directly with the FIDs is that it reduces the need for controls and menus in basic navigational tasks such as scrolling.

Thumb Slide

The occlusion of IR reflectors from the camera's view allows each reflector to function as a button that can be pressed at any time. The thumb of the user's dominant hand can be used to click by covering one of three IR reflectors in the center of the FID (see Figure 2). This technique is often used in tandem with more complex folding gestures to create sophisticated interaction scenarios, such as to pick up and hold Sheets.

When interacting with Sheets the user can also use their fingers to occlude varying numbers of IR reflectors on the FID, allowing their use as buttons or triggers for assorted GUI controls such as popup menus.

Scoop Shape

FIDs can be molded in the palm of the user's dominant hand to form a scoop, which naturally affords containment and moving of other objects such as Sheets. The scoop shape is released by flattening the FID.

Top Corner Bend

Each top corner of the FID can be bent in excess of 90 degrees. It is possible to differentiate the two corners so that each corner can be reserved for different functionality. The top corners are easier to bend and are the only two active corners. This is because the bottom corners require use of the thumb and would normally be

used to hold the FID. Bending a corner of the FID has a strong affordance of earmarking or book-marking Sheets, as well as paging.

Hover

When the user raises the FID, the camera can detect the change in size of the FID, giving an indication of its distance. This technique is often used to augment the scoop technique, allowing users, for example, to magnify information on a Sheet by bringing it closer.

Fold

Using either one or both hands, users can fold the Folding FID up to 180 degrees along one axis, which the software detects by measuring the total area of visible IR reflectors. This metric gives an accurate indication of the fold angle. It can be linked to a large number of FUI actions; one of the most practical is the origami folding of a textured Sheet.

Leafing

This is a two-handed multi-stage technique. First the user places his or her left thumb over the left center IR reflector, and then their right thumb over the right center IR reflector. When the right side of the FID is bent away from the user and the right thumb released, a leafing action is triggered. This action can be associated with paging through Sheets.

Shake

The FID can be shaken to trigger various discrete events, such as sorting. The shake is detected by measuring the oscillation of IR reflectors on the FID across the camera viewing plane within a set timeframe.

Squeeze

When holding the FID in the palm of one hand or cupped between two hands, the FID can be squeezed into either a concave or convex shape. Detecting this is accomplished by tracking changes in the aspect ratio of the FID and the lengths of the leftmost, center, and rightmost columns of IR reflectors.

FIDs IN FOLDABLE UI INTERACTIONS

FIDs are capable of carrying out many useful tasks in our Foldable UI. They can be used to navigate the desktop, and to select, stack, sort, annotate and browse documents.

Navigation

To navigate the desktop, an FID can be picked up and moved in the camera's viewing plane, or slid around on the desk. The Transparency reflects the exact position and shape of the FID.

Selection

Sheets can be activated and picked up by the FID by hovering a Transparency over a Sheet, then scooping the FID with a Thumb Slide covering the two bottom center IR reflectors. As soon as the thumb is removed, the Sheet is dropped. While a Sheet is selected, sliding the thumb further forward onto the third central IR reflector will lock the selection in place, allowing the user to uncover

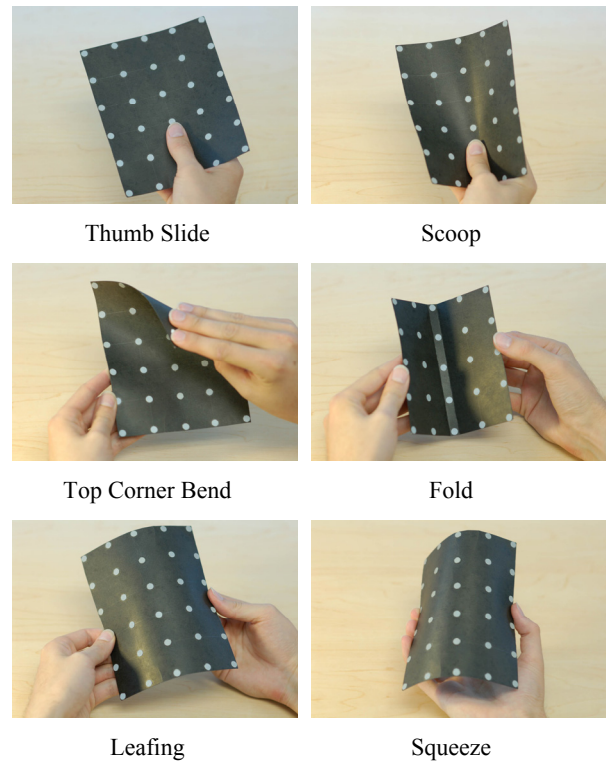


Figure 2. FID Interaction Techniques

all IR reflectors while maintaining the selection. To release a locked selection, the thumb can be slid forward a second time onto the third center reflector.

Sorting

While holding multiple FIDs that are linked to separate Sheets, a brief shake will cause the Sheets to be resorted. The default sort is alphabetical by title, but other sorting criteria can be selected from a popup menu activated by a Thumb Slide. The stack of FIDs will subsequently represent the new order of Sheets.

Origami

The folding technique can be used to transform the Sheet into a new shape, either to adjust the geometry (see Fig. 3) of the Sheet or to highlight an important section. This is a useful technique for implementing 3D transformations because the FIDs provide organic feedback in real time and as the fold is occurring. Folding of Sheets into complex shapes can be done in a series of fluid movements. Folds are made permanent using a brief Shake gesture.

Browsing

The leafing technique is used to browse through, and reveal, the next page in a document. This effect closely mirrors what happens when a person leafs through a collection of pages, or a book.

Corner bending can be used to scroll the contents of lengthy documents by bending the top right corner gently towards or away from the user.

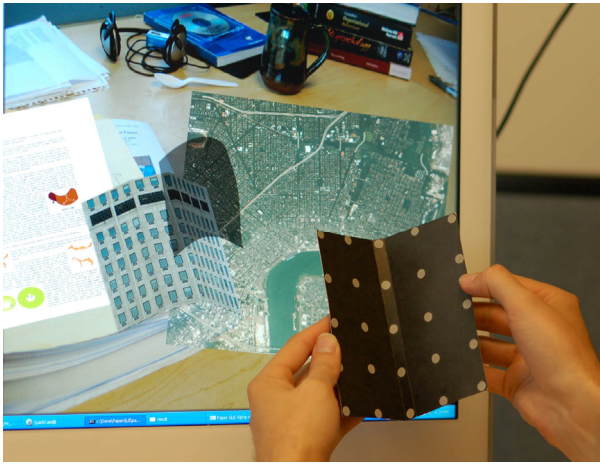


Figure 3. Origami folding task with office tower texture.

Zooming

Sheets can be resized to make content appear larger or smaller. This is accomplished using the Hover technique. To temporarily freeze the zoom level, the thumb slide technique is used to trigger a freeze button. To release the freeze, the user presses the zoom freeze button again.

Zooming can also be applied to a sub-section of a Sheet using the squeeze technique. If a Sheet contains a map, the Transparency can be used to select an area to zoom in upon. When the FID is squeezed into a concave shape, the area covered by the Transparency magnifies to fill the entire Sheet. From there, the user can either zoom in again, or zoom out by using the squeeze technique to form a convex shape.

CONCLUSIONS

In this paper we presented the Foldable Input Device (FID), a prototype Organic User Interface that leverages the physical properties of paper to create a more organic input experience, using paper as a metaphor for interaction. At the disposal of the user is a diverse lexicon of interaction techniques, including folding, scooping, bending, shaking, squeezing, and hovering. These techniques can be combined to carry out FUI tasks such as navigation, selection, sorting, stacking, browsing, and folding.

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