Deformable User Interfaces: Using Flexible Electronics for Human Computer Interaction

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***Abstract*— Deformable inputs offer users the ability to physically manipulate a device for system interaction. We combine flexible electronic technologies with human computer interaction to study how changing the form factor of digital devices can offer new interaction techniques to users. We introduce our research on deformable user interfaces by discussing bend gestures as a source of input, presenting our process to rapidly prototype flexible devices, and demonstrate three deformable user interfaces: bend passwords, bend for mobile games, and bend for vision impaired users. We show how flexible devices and deformable interactions can improve how we interact with our devices.**

Keywords—Human Computer Interaction, Deformable User Interfaces, Flexible Electronics

I. Introduction

It is becoming evident the next generation of displays will be flexible, having made their way from research prototypes to consumer products [1]. They are lightweight, flexible and thin, and interactive. Emerging flexible technologies enable a multitude of flexible interactive devices, covering a range of modalities; from those resembling paper documents to others like the newest smartphones. Beyond being interesting new pieces of technology, it is necessary to investigate how people will interact with flexible devices. How are these interactions different from those with rigid devices? What form factors would create better interactions? Are there specific contexts, applications, or user populations that could benefit most from flexible devices, with or without displays? How should we design for them? Are there scenarios or spaces where flexible devices are not appropriate? These research questions are critical to creating a successful user experience when interacting with a device. It is crucial to start addressing them in parallel to the design and the development of the technology.

These research questions stem from the field of Human Computer Interaction (HCI), which puts users first, and considers and investigates how users will adopt, learn, and interact with digital devices and interfaces. Deformable User Interface (DUI) research focuses on flexible technology [2], [3], and investigates how the flexibility and deformability of digital devices can be exploited to offer new interaction techniques to users. For instance, we can bend the corner of an ebook reader to change the page [4], or squeeze a phone to answer it [5].

In this paper, we focus on the research question: can flexible input improve how we interact with our handheld devices? Our research investigates the design and evaluation of new input and interaction techniques for this new generation of interactive devices. We present research on deformable user interfaces conducted at the Creative Interactions Lab at Carleton University, discussing interaction techniques and showing various applications of such deformable flat UIs such as bend passwords, game input, and targeting vision impaired users.

Figure 1. Flexible devices offer deformation as a source of input. In this game, bending the top right corner towards the user fires a paper arrow [6].

II. Advances in User Interaction using Deformation

With the advent of smartphones, rigid handheld devices have enabled an unprecedented level of interaction for users. However, there are a number of issues with our rigid devices that prevent ideal use: the partial occlusion of the display by our fingers during interaction, the limited reachability of interactions areas due to the growing size of smartphones, the unavailability of touch in certain contexts (e.g., due to wearing gloves, or to sensing and mobility disabilities) [7].

We believe that flexible devices can solve some of those issues. Flexible devices offer deformation as a source of input, at time in complementarity to current sources of input such as touch, buttons, or tilt. Specifically, we focus our research on bend gestures. Bend gestures are created by the curvature of a portion of a flexible device (e.g. upwards bend of the top right corner of a flexible smartphone, Figure 1) [9], [10]. Bend gestures are classified by the gesture location (e.g. top corner or side fold), direction (towards the user, or away from the user), the size of the bend area, the angle, the edge, the speed and duration of the bend [10]. These gestures can include both

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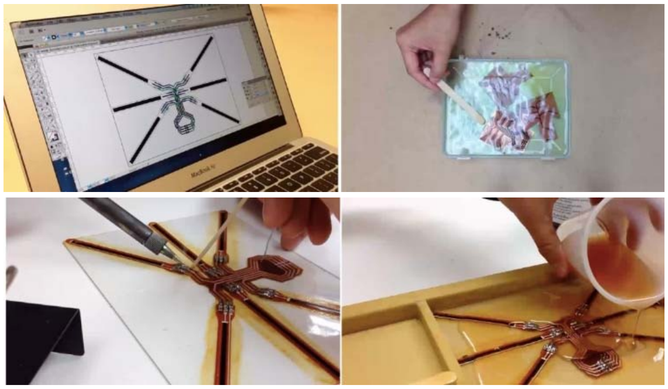

Figure 2. Our rapid fabrication process: (a) drawing the circuit, (b) etching the circuit, (c) soldering the components, and (d) encasing the prototype in silicone [8].

one and two-handed interactions [5]. Bending the device allows the user to interact with their device with minimal occlusion as the hands stay on the periphery of the device.

A. Prototyping Flexible Devices in HCI

As HCI researchers, our goal is to provide better tools for users to interact with digital information. When creating our prototypes, we use a rapid prototyping method that allows us to iterate quickly to produce a prototype that allows the assessment of interaction techniques, form factors and applications. We developed a relatively inexpensive method for HCI researchers to create and customize deformable prototypes that use flexible printed circuits with commercial flexion sensors [8]. Figure 2 illustrates the basic steps of this process, which is easily repeatable and works for a variety of materials.

We also use maker tools (e.g. 3d printing and moulding). We balance various considerations when developing our prototypes: form factor (size and shape of the device), ergonomics (stiffness and comfort), sensing requirements (e.g. flexion, stretch) [8]. We iterate quickly through our prototypes to find one that optimizes our design constraints. Figure 3 shows a series of prototypes produced through rapid iterations to reach the required design considerations of our prototype.

This iterative process, combined with sometimes complex form factor considerations leads us to produce prototypes that can use functional flexible displays or prototyped displays (e.g. using projection on a flexible plastic substrate), both augmented with flexion sensors, to enable the dynamic physical manipulation of information.

Figure 3. Iterating through prototypes in silicone lets researchers achieve quickly the correct design considerations of form factor, ergonomics and sensing requirements.

B. Applications

Our work in this field started with the creation of PaperPhone, the first smartphone-inspired fully functional flexible E Ink prototype that uses bend gestures as input [9]. Following this, we investigated numerous applications suitable for bend input, from basic smartphone applications such as music players and icon navigation (e.g. [5]) to developing tools for users with physical impairments (e.g. with blind users [11]). We illustrate three areas here: bend passwords, bend in mobile gaming, and bend as input for blind users.

Bend passwords are a novel authentication scheme that uses bend gestures as input modality [12]. Bend passwords are composed of a series of bend gestures on a flexible smartphone from 20 possible gestures defined by the location of the bend, (which corner(s) of the device is manipulated), and on the direction of the bend (towards or away from the user) [10]. Through three user studies to evaluate their usability and security, we demonstrated that bend passwords are more secure and as memorable as PIN passwords. In a shoulder surfing study, we also showed that people did not possess the current mental models to steal a bend password.

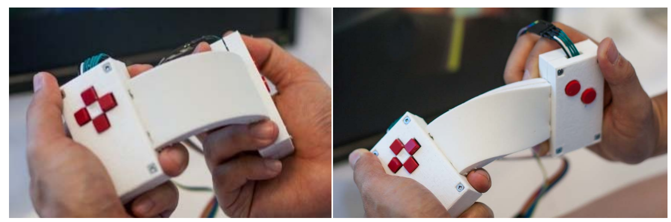

Figure 4. Bending and twisting input for our bendable game controller.

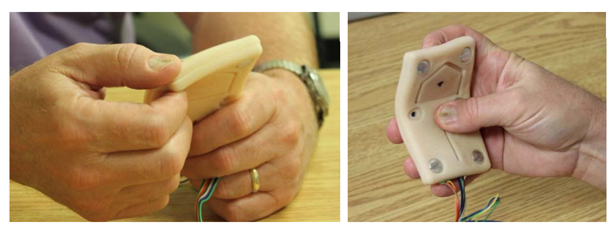

Figure 5. Typhlex, a flexible prototype designed for blind users.

We used a novel game controller, Bentroller (Figure 4), to explore *mobile gaming with flexible devices*. Bendtroller adds a flexible bridge to a rigid standard controller [13]. In addition to button input, users can perform four deformation gestures by bending and twisting the bridge. We evaluated this controller with two user studies to investigate the appropriateness, efficiency and user experience of three action mappings (using only buttons; using buttons for navigation and deformation for actions (e.g. jumping); and using buttons for actions and deformation for navigation). In all studies, we found that users enjoyed mapping special actions to the novel gestures.

Flexible devices also show promise for *vision impaired users.* This research aims to understand if deformation as an alternative tactile interaction experience could enhance the accessibility of technology for blind users. A preliminary study comparing touch and bend with simulated visually impaired users demonstrated such potential [11]. We then compared our prototype with a smartphone by asking blind users to browse a mobile website performing a series of common tasks while controlling a screen reader (Figure 5). Bend gestures were easily understood, performed, and enjoyed by our blind participants, and the gestures provided a more familiar mapping to screen- reading actions than touch-based interaction.

III. Conclusion

In this paper, we demonstrate that deforming and reshaping devices, such as dynamically changing the device's form factor, is a promising trajectory for handheld devices. We use the examples of Bend passwords, a novel authentication scheme for flexible devices, and Bendtroller, our deformable game controller, to introduce bend gestures as a meaningful input for flexible mobile devices and show that flexible devices and deformable interactions can improve how we interact with our devices. Finally, we show that the tactile nature of gripping and bending a deformable device, Typhlex, can be useful for specific users, such as people who are visually impaired.

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References

[1] A. Nordrum, "Fold-up screens could make their big debut [Top Tech 2017]," *IEEE Spectr.*, vol. 54, no. 1, pp. 50–51, 2017.

[2] G. Herkenrath, T. Karrer, and J. Borchers, "Twend: Twisting and Bending as new Interaction Gesture in Mobile Devices," in *SIGCHI Conference Extended Abstracts on Human Factors in Computing Systems*, 2008, pp. 3819–3824.

[3] J. Kildal, "Interacting with Deformable User Interfaces: Effect of Material Stiffness and Type of Deformation Gesture," in *Haptic and Audio Interaction Design*, 2012, pp. 71–80.

[4] J. Watanabe, A. Mochizuki, and Y. Horry, "Bookisheet: Bendable Device for Browsing Content Using the Metaphor of Leafing Through the Pages," in *Proceedings of the 10th international conference on Ubiquitous computing - UbiComp '08*, 2008, p. 360.

[5] A. Girouard, J. Lo, M. Riyadh, F. Daliri, A. K. Eady, and J. Pasquero, "One-Handed Bend Interactions with Deformable Smartphones," in *SIGCHI Conference on Human Factors in Computing Systems*, 2015, pp. 1509–1518.

[6] E. Fares, V. Cheung, and A. Girouard, "Effects of bend gesture training on learnability and memorability in a mobile game," in *Interactive Surfaces and Spaces*, 2017, pp. 240–245.

[7] N.-H. Yu, D.-Y. Huang, J.-J. Hsu, and Y.-P. Hung, "Rapid Selection of Hard-to-Access Targets by Thumb on Mobile Touch-Screens," *Proc. MobileHCI*, p. 400, 2013.

[8] J. Lo and A. Girouard, "Fabricating Bendy: Design and Development of Deformable Prototypes," *IEEE Pervasive Comput. Spec. Issue Fabr. Print.*, vol. 13, no. 3, pp. 40–46, 2014.

[9] B. Lahey, A. Girouard, W. Burleson, and R. Vertegaal, "PaperPhone: Understanding the use of bend gestures in mobile devices with flexible electronic paper displays," in *SIGCHI Conference on Human Factors in Computing Systems*, 2011, pp. 1303–1312.

[10] K. Warren, J. Lo, V. Vadgama, and A. Girouard, "Bending the rules: Bend gesture classification for flexible displays," in *SIGCHI Conference on Human Factors in Computing Systems*, 2013, pp. 607–610.

[11] M. Ernst, T. Swan, V. Cheung, and A. Girouard, "Typhlex: Exploring Deformable Input for Blind Users Controlling a Mobile Screen Reader," *IEEE Pervasive Comput.*, vol. 16, no. 4, pp. 28–35, Oct. 2017.

[12] S. Maqsood, S. Chiasson, and A. Girouard, "Bend passwords: Using gestures to authenticate on flexible devices," *Pers. Ubiquitous Comput.*, vol. 20, no. 4, pp. 573–600, 2016.

[13] P. Shorey and A. Girouard, "Bendtroller: An exploration of in-game action mappings with a deformable game controller," in *SIGCHI Conference on Human Factors in Computing Systems*, 2017, pp. 1447–1458.