Exploring Eyes-free Interaction with Wrist-Worn Deformable Materials

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Abstract

Recent work has explored how on-the-wrist devices can be augmented with displays, sensors, and aesthetics to produce a new genre of wearable, digital jewelry. Most often, these devices are augmented with hardware (e.g., touch-screens, gyroscopes) to receive wearer input. Breakthroughs in sensing materials allow novel inputs such as squeeze, bend, and stretch, which may be more suited to interaction with a discreet wearable.

We explore interactions with a flexible bracelet that can be manipulated through bend, stretch, and touch. We discuss the process involved in fabricating materials that convert these actions into measurable parameters. We particularly focus on eyes-free interactions with bracelets that take advantage of the tactile feedback from the act of deformation, and demonstrate some early, low-fidelity prototype concepts.

Author Keywords

Wearables; Deformation User Interaction; Bracelets; Digital Jewelry.

ACM Classification Keywords

H.5.2. Information interfaces and presentation: User Interfaces – Interaction styles, prototyping.

Introduction

Wearables are digital devices that can be worn on the body. They are typically equipped with sensors (e.g., pedometer, heart-rate monitor) and displays (e.g., LCD screen, LED light), and are often used for tasks like tracking personal biometrics in real-time or recording and analyzing daily activity. Besides being a popular research area in HCI, wearables are also receiving tremendous attention from sectors such as personal behaviour monitoring and healthcare [12].

One popular category of wearables is on-the-wrist devices (OWDs), which resemble watches or bracelets. OWDs benefit from the wrist being an easily accessible and socially acceptable site of interaction [20]. As a personal device, OWDs can also be regarded as fashion objects, and designers can explore their aesthetics in addition to interactions [19]. Emerging sensing materials and fabrication techniques allow new methods of interacting with wearable devices, which are different from most existing approaches to interactive wearables (e.g., [16,21]) in that actions applied to the structural materials (e.g., band of a smartwatch) can be sensed as user inputs; bringing robust, eyes-free interactions to OWDs. This area has not been well explored and may offer other advantages such as reducing power use, fabrication costs, and the bulkiness of devices.

In this paper we turn our attention to the current state of on-the-wrist devices, and to new materials and fabrication processes available. We contribute by presenting our early, low-fidelity deformable on-the-wrist prototypes, and an interaction language applicable to these devices. We also discuss the implications, and propose a testing plan for the utility of eyes-free deformable on-the-wrist wearables.

Related Work and Design Choices

We begin with the current state of on-the-wrist devices in academia and industry, and how they inspire our exploration in deformable OWDs. Next we examine examples of potential materials and sensors in fabricating deformable OWDs. We then discuss the considerations that informed our design of interactions for OWDs, such as eyes-free interaction and the involvement of both the wearing and activating hands.

Wearables and On-the-Wrist Devices

Researchers have used OWDs to gather data and communicate with the wearer. For example, Lyons et al. [16] created Facet, a bracelet comprising multiple segments featuring touch-screen displays, allowing its wearer to manage different levels of information detail from several applications. Fortmann et al. [6] proposed integrating LEDs for information display, along with sensors for data capture and buttons for user interaction into charms and gems on a bracelet, and recommended that device aesthetics and personal customization should be considered in OWD design.

Commercial "smart bracelets" are information focused but handle information display in diverse ways. For example, FitBit Flex2 [5] features notification lights, rather than the full displays found on smart watches like the Apple Watch [1]. In between are OWDs like the Under Armor Band [28], which have embedded, specialized displays. The use of different sensing and display components in OWDs must balance the ability to gather and convey information while maintaining a form appropriate to a wrist-worn device; increased size or bulky additions can lead to usability issues [21]. This is especially true for devices in the form of bracelets, which should not hinder common hand movements [6].

Besides what and how data are presented on an OWD, how people interact with OWDs is another area of research interest, especially regarding the novel interaction techniques enabled by their form and functionality. Pakanen et al. [21] designed Squeezy Bracelet as a communication device, where wearers squeezed pipets to create, read, and send messages. Tarun et al. [27] proposed Snaplet, which used bends on a bracelet display to determine context of use and user input. Perrault et al. [24] created WatchIt using resistive potentiometers on the wristband of a smartwatch for finger control, to support eyes-free interaction. These three works have inspired our initial design, where we propose to create a deformable on-the-wrist device for eyes-free interaction.

Materials and Fabrication Methods

Researchers have investigated the use of deformable materials as user interfaces (e.g., [3,14,23]), and have suggested that these novel materials could generate intuitive and adaptive interaction techniques. We have identified several materials and fabrication techniques applicable to the context of on-the-wrist devices.

Stretch/Pressure sensors made from conductive polymers offer simple interaction through deformation. The resistance of the sensor changes as it is stretched/pressed, giving a measurement of the magnitude of deformation (e.g., tension and stretch [17], pressure [18]). Similarly, carbon black pigment can be used with silicone rubber or other polymers to create custom conductive elements suitable for detecting touch [9] or strain [13]. Other methods of making stretch/touch sensors include printing conductive ink onto flexible substrates [29], and embedding optical sensors to detect transmissivity changes in elastic fabric [26]. Stretch and pressure are two interesting inputs that have not been explored in the context of interacting with the structural materials of an OWD.

Bend sensors have been used in wearables focusing on the hand and wrist [11]. These sensors, both uni- and bi-directional, can be used to detect deformations along one axis in specific parts of a deformable device. In the context of OWDs, they could be used to create discrete interaction areas within the device.

Breakthroughs in **deformable circuits** have facilitated robust fabrication of deformable OWDs. Researchers have used flexible circuits [15] and flexible displays [7] to create deformable mobile devices. The combination between these technologies and stretchable circuit technology [22] offers the potential for deformable OWDs being both bendable and stretchable.

Interacting with Deformables

An interesting characteristic uniquely afforded by deformable user interfaces is the provision of non-visual and tactile feedback through force/tension and people’s understanding of the spatial positioning of their hands. For example, stretching a band creates tension that the user can feel. Once learned, we often rely on this spatial knowledge and tactile feedback to perform complex tasks without looking, like tying a shoelace. This drives the concept of eyes-free interaction, where the user “*can interact confidently in the absence of graphical feedback”* [20:126]. We focus on the input modalities of eyes-free interaction supported by the deformable materials used to create OWDs, as discussed in the next section.

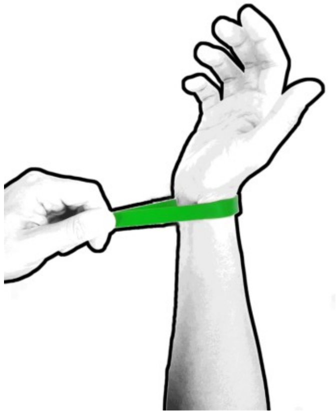


Figure 1. Interacting with a deformable on the wrist device: Pinching-along and pulling.

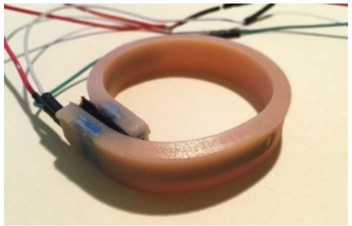


Figure 2. Exploratory prototype with embedded bend sensor.

Designing Eyes-Free Interactions for OWDs

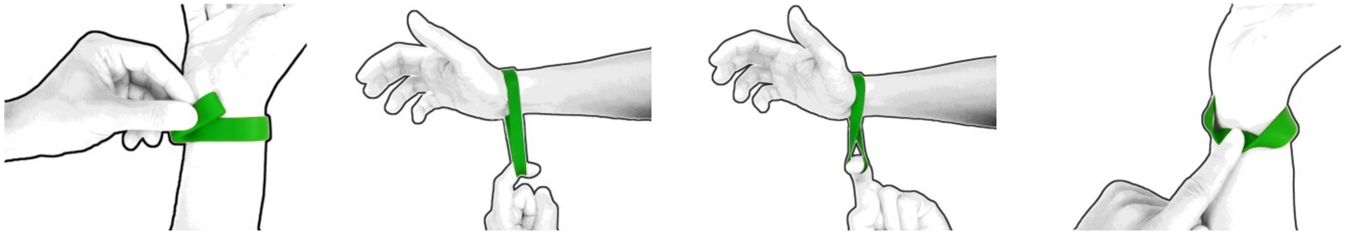
In the context of deformable OWDs (e.g., bracelets), the wearing hand serves as an anchor to provide a fixed point or counter force to the actions of the activating hand. In designing interactions for OWDs, the style of interaction is often no longer purely one-handed, as it is with the Squeezy Bracelet [21] or most non-deformable wearables [16,24]. For example, the force of the tension created in stretching or pulling the device necessitates the wearing hand to perform a counter, or balancing force, typically from the opposite wrist, to support successful deformation. This may offer opportunities similar to the structural holds that have been identified in flexible display interactions [4].

Interestingly, deformable devices designed for use on the hand and wrist typically assume forms that designate the wearing hand also as the activating hand (e.g., [8,10,25]). This would not be possible for a deformable OWD, as locating the device fully on the wrist makes its accessibility to the wearing hand uncomfortable or impossible more most people.

For intentional interaction, we believe that the material properties of deformable devices are best utilized when both hands are involved (Figure 1). This is different from sensor augmentation which does not require bimanual interaction, as we see with wearable devices in the existing literature (e.g., [16,21]). Yet, to our knowledge, none have looked at interaction languages for deformable wearables.

In view of such discrepancy, we developed an interaction language that captures the fundamental actions available for bimanual eyes-free interactions for OWDs. We began with informal brainstorming sessions within our research group with various expertise in interaction design and fabrication by putting elastic bands (flat, slightly loose) on our wrists, and freely manipulated the bands. This method was similar to that used by Lee et al. [14], where participants were provided with deformable materials (paper, plastic, cloth), to elicit deformation-based gestures. However, we did not target any specific tasks to gain a better understanding of what actions an OWD afforded. The basic motion types we found were consistent with those identified by Lee et al. using an elastic cloth (except crumpling), and with a few additional interactions more specific to bands (e.g., pinching). We then adapted and summarized these gestures into our interaction language for OWDs, as illustrated in Figure 3.

This language highlights the partial bimanual nature of the actions using separate descriptions of the activating hand (AH) and wearing hand (WH). We use this notion instead of “dominant” and “non-dominant” hands, as these actions can be performed by either, and are dependent on which hand is wearing the device. To provide more context, this language includes measurable parameters for implementation, such as magnitude and direction of bend and stretch, as well as force of pressure. Using these parameters, designers can choose between discrete inputs (e.g., binary through a threshold value) and continuous inputs (e.g., mapping of magnitude of bend to a range of values).



Bending/Folding

AH’s fingers apply force at two ends, device forms an arc, or a loop when the ends touch. Measurable as magnitude of bend.

Stretching

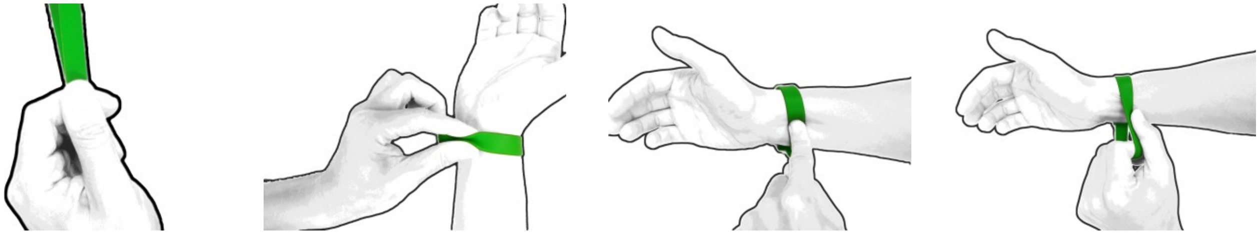
AH’s finger(s) forms a hook and pulls part of the device away from the WH, which functions as an anchor to maintain the tension. Measurable as magnitude of stretch.

Twisting

AH’s finger(s) forms a hook under the device and turn. WH functions as an anchor to provide a counter force in the twist. Measurable as angle of rotation.

Rolling

AH’s finger(s) presses on the device against WH, and rubs in a direction. WH functions as a surface to provide friction and support to the motion. Measurable as angle and location of rotation.



Pinching-along

AH’s fingers pinch part of the device and press together. It is different from Bending/Folding where the ends of the action are further apart. Measurable as force of pressure.

Pinching-across

AH’s fingers pinch part of the device and press together. It is similar to Pinching-along but in a different direction. Measurable as force of pressure.

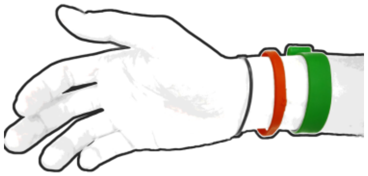
Squeezing

AH’s finger(s) apply pressure on to a part of the device. WH functions as a surface to provide a normal force against the motion. Measurable as force of pressure.

Touching

Both AH and WH work in tandem to create a rigid surface for the AH’s thumb to touch/slide on. Measurable as magnitude of stretch and force of pressure.

Figure 3. Illustration of eyes-free interactions for an on-the-wrist device (OWD). We highlight the roles of the Activating Hand (AH) and Wearing Hand (WH) in the partial bi-manual interaction commonly found in the actions: AH serves as the hand performing the named action, and in some actions the WH is the necessary anchor to complete the action. These actions do not distinguish dominant and non-dominant hands.



Band shapes: round and thin, flat and narrow, flat and wide.

Band with bend sensor.

Band with stretch sensor.

Figure 4: Forms and sensor augmentation for low-fidelity, deformable OWDs.

We also note the possibility to combine some of the deformation actions, as well as additional actions when the device is worn differently. For example, a person can pinch-along and stretch the device at the same time, forming a pull action (Figure 1), or shift a loosely worn device along one's arm. For simplicity, we limit our current vocabulary to those that involve bending and/or stretching, and leave the combinations and other wearing styles for future iterations of the interaction language.

In summary, the actions in the language are applicable to a wide range of OWDs, from bands of different widths to different tightnesses, as long as they afford bending and stretching deformations. Yet, some actions might be easier to perform if the device has some width and is worn loosely on the wrist: similar to the setup we used during the informal brainstorming sessions when developing the interaction language.

Prototyping and Exploration

We have identified two areas of exploration to begin describing the potential of deformable on-the-wrist devices: fabrication and interaction. As a technical challenge, we will apply the materials and methods used in deformable device prototyping and fabrication to create devices capable of detecting and capturing an array of deformation-based interactions. Along with this, we will use the experience prototyping technique described by Buchenau and Suri [2] to identify the interactions best suited to deformable OWDs, drawing from the preliminary interaction set that we have identified here. We believe this technique is more appropriate for initial exploration on informing research and discovery; rather than the observational technique used by Lee et al. [14], which is more suitable for designing gestures and interfaces with a given set of commands. We will then identify and explore possible applications for these devices.

We will employ low-fidelity prototypes; silicon rubber bands of various shapes, fitted with bend and stretch sensors; to explore possible interactions that will inform both the design of higher fidelity, sensing prototypes and the interactions that we will test with users.

Demonstration

During the conference, we will present low- and medium-fidelity prototypes (e.g., Figure 2, Figure 4) demonstrating a selection of materials, fabrication techniques, and embedded sensors. It is our intention to provoke discussion, exchange ideas, and foster collaboration opportunities at the conference.

Conclusion

Wearables, and particularly on-the-wrist devices, are gaining attention in areas like personal behaviour monitoring and healthcare [12]. We believe that deformation-based interactions and materials are suited to OWDs. We propose to explore the fabrication of deformable OWDs, and to use these prototypes to build on and validate a deformation-based eyes-free interaction language for on-the-wrist devices.

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References

[1] Apple Inc. Watch. 2016. http://www.apple.com/watch/.

[2] Buchenau, M. and Suri, J. Experience prototyping. *Designing Interactive Systems*, (2000), 424–433.

[3] Chien, C., Liang, R.-H., Lin, L.-F., Chan, L., and Chen, B.-Y. FlexiBend: Enabling Interactivity of Multi-Part, Deformable Fabrications Using Single Shape-Sensing Strip. *ACM Symposium on User Interface Software & Technology*, (2015), 659–663.

[4] Dijkstra, R., Perez, C., and Vertegaal, R. Evaluating effects of structural holds on pointing and dragging performance with flexible displays. *SIGCHI Conference on Human Factors in Computing Systems*, ACM Press (2011), 1293–1302.

[5] Fitbit Inc. Fitbit Flex 2™ Fitness Wristband. 2016. https://www.fitbit.com/ca/flex2.

[6] Fortmann, J., Root, E., Boll, S., and Heuten, W. Tangible Apps Bracelet: Designing Modular Wrist-Worn Digital Jewellery for Multiple Purposes. *ACM Conference on Designing Interactive Systems*, (2016), 841–852.

[7] Gotsch, D. HoloFlex : A Flexible Holographic Smartphone with Bend Input. *CHI Extended Abstracts on Human Factors in Computing Systems*, (2016), 3675–3678.

[8] Hoang, T.N., Smith, R.T., and Thomas, B.H. Passive Deformable Haptic glove to support 3D interactions in mobile augmented reality environments. *2013 IEEE International Symposium on Mixed and Augmented Reality, ISMAR 2013*, (2013), 257–258.

[9] Holman, D., Fellion, N., and Vertegaal, R. Sensing Touch Using Resistive Graphs. *Proceedings of the 2014 conference on Designing interactive systems - DIS '14*, (2014), 195–198.

[10] Kang, B.B., Lee, H., In, H., Jeong, U., Chung, J., and Cho, K.J. Development of a polymer-based tendon-driven wearable robotic hand. *Proceedings - IEEE International Conference on Robotics and Automation 2016–June*, (2016), 3750–3755.

[11] Kim, D.H. and Park, H.S. Thumb joint angle estimation for soft wearable hand robotic devices. *IEEE International Conference on Rehabilitation Robotics 2015–Septe*, (2015), 91–94.

[12] Kinnaird, P. and Talgam-Cohen, I., eds. Wearable Computing: Getting Dressed in Tech. *XRDS 20*, 2 (2013).

[13] Kumbay Yildiz, S., Mutlu, R., and Alici, G. Fabrication and characterisation of highly stretchable elastomeric strain sensors for prosthetic hand applications. *Sensors and Actuators A 247*, (2016), 514–521.

[14] Lee, S.-S., Kim, S., Jin, B., et al. How users manipulate deformable displays as input devices. *SIGCHI Conference on Human Factors in Computing Systems*, (2010), 1647–1656.

[15] Lo, J. and Girouard, A. Fabricating Bendy: Design and Development of Deformable Prototypes. *IEEE Pervasive Computing Special Issue on Fabrication and Printing 13*, 3 (2014), 40–46.

[16] Lyons, K., Nguyen, D., Ashbrook, D., and White, S. Facet: A Multi-Segment Wrist Worn System. *ACM Symposium on User Interface Software & Technology*, (2012), 123–130.

[17] Mattmann, C., Clemens, F., and Tröster, G. Sensor for measuring strain in textile. *Sensors 8*, 6 (2008), 3719–3732.

[18] Mei, H., Wang, R., Wang, Z., Feng, J., Xia, Y., and Zhang, T. A flexible pressure-sensitive array based on soft substrate. *Sensors & Actuators: A. Physical 222*, (2015), 80–86.

[19] Miner, C., Chan, D., and Campbell, C. Digital jewelry: wearable technology for everyday life. *Extended Abstracts on Human Factors in Computing Systems*, (2001), 45–46.

[20] Oakley, I. and Park, J.-S. Designing Eyes-Free Interaction. In *Haptic and Audio Interaction Design*. 2007, 121–132.

[21] Pakanen, M., Colley, A., Häkkilä, J., Kildal, J., and Lantz, V. Squeezy Bracelet -Designing a Wearable Communication Device for Tactile Interaction. *Nordic Conference on Human-Computer Interaction*, (2014), 305–314.

[22] Panasonic Corporation. Panasonic Develops a Stretchable Resin Film and Its Application Materials For Stretchable Electronics | Headquarters News | Panasonic Newsroom Global. *Press Release*, 2015, 1. http://news.panasonic.com/global/press/data/2015/12/en151224-3/en151224-3.html.

[23] Panëels, S. and Strachan, S. Exploring Interactions with a Flexible Tactile Device for Multi-Context Interaction. *Extended Abstracts on Human Factors in Computing Systems*, (2016), 2632–2639.

[24] Perrault, S.T., Lecolinet, Eagan, J., and Guiard, Y. Watchit: simple gestures and eyes-free interaction for wristwatches and bracelets. *SIGCHI Conference on Human Factors in Computing Systems*, (2013), 1451–1460.

[25] Strohmeier, P., Vertegaal, R., and Girouard, A. With a flick of the wrist: Stretch Sensors as Lightweight Input for Mobile Devices. *Proceedings of the Sixth International Conference on Tangible, Embedded and Embodied Interaction - TEI '12*, (2012), 307.

[26] Sugiura, Y., Inami, M., and Igarashi, T. A thin stretchable interface for tangential force measurement. *User Interface Software and Technology*, (2012), 529–536.

[27] Tarun, A.P., Burleson, W., Environments, M., Lahey, B., Girouard, A., and Vertegaal, R. Snaplet : Using Body Shape to Inform Function in Mobile Flexible Display Devices. (2011), 329–334.

[28] Under Armor Inc. Under Armour UA Band | Sleep Fitness Tracker | US. 2016. https://www.underarmour.com/en-us/ua-band.

[29] Wessely, M., Tsandilas, T., and Mackay, W.E. Stretchis : Fabricating Highly Stretchable User Interfaces. *User Interface Software and Technology*, (2016), 697–704.