# Bendable Color ePaper Displays for Novel Wearable Applications and Mobile Visualization

Konstantin Klamka
Interactive Media Lab, Technische Universität Dresden
Dresden, Germany

Raimund Dachselt*
Interactive Media Lab, Technische Universität Dresden
Dresden, Germany


**Figure 1: Our bendable color ePaper toolkit (A) enables novel, fully-functional wearable and mobile DataVis applications (B).**

## ABSTRACT

This paper presents a toolkit that allows to easily prototype with *bendable color ePaper displays* for designing and studying novel body-worn interfaces in mobile scenarios. We introduce a software and hardware platform that enables researchers for the first time to implement fully-functional wearable and UbiComp applications with interactive, curved color pixel displays. Further, we provide a set of visual and sensory-rich materials for customization and mounting options. To technically validate our approach and demonstrate its promising potential, we implemented eight real-world applications ranging from personal information and mobile data visualizations over active notifications to media controls. Finally, we report on first usage experiences and conclude with a research roadmap that outlines future applications and directions.

## KEYWORDS

Color, ACeP, EPD, ePaper, E-Ink, electrophoretic, flexible, bendable, StrapDisplay, wearable, personal InfoVis, HCI, toolkit, mobileVis

*Also with, Centre for Tactile Internet with Human-in-the-Loop (CeTI), Technische Universität Dresden, Germany.

*UIST '21 Adjunct, October 10–14, 2021, Virtual Event, USA*
© 2021 Copyright held by the owner/author(s). Publication rights licensed to ACM.
This is the author's version of the work. It is posted here for your personal use. Not for redistribution. The definitive Version of Record was published in *The Adjunct Publication of the 34th Annual ACM Symposium on User Interface Software and Technology (UIST '21 Adjunct), October 10–14, 2021, Virtual Event, USA*, https://doi.org/10.1145/3474349.3480213.

## 1 INTRODUCTION & BACKGROUND

Ultra-thin and flexible display technologies are key enabling factors for innovations in HCI. They make it possible to explore novel interfaces and visualizations that go beyond traditional form factors.

Therefore, manufacturing approaches for color-changing and light-emitting ambient displays using *chromic structures* (e.g., electro- [24, 46], thermo- [10], photochromic [25, 51]) or *luminescent materials* (e.g., electroluminescence [19, 26, 36]) have been investigated. While these are often characterized by single-color and segment-based or low-resolution designs, future wearable applications will also require pixel-based displays providing more dynamic capabilities. Unfortunately, flexible high-resolution OLED screens are rarely accessible, need constant energy and complex drivers (cf. [16]).

As a promising alternative, electrophoretic E-Ink/ePaper displays have been established as well-suited flexible, robust and bi-stable pixel screens. Prior research using bendable ePaper ranges from paper tabs [48], situated displays [18], foldable devices [17, 30, 37] over bracelets [9, 45, 49] and watch bands [29, 41] to bag straps [50] and on-clothing displays [11, 20, 28, 34]. While such examples show great potential, they, however, lack color since most ePaper displays *either* provide bendable capabilities *or* support color.

With this work, we present the first platform that allows to prototype with interactive, ultra-thin ePaper displays supporting both: bendable *and* color capabilities (see Figure 1, A). Therefore, we contribute an easy-to-use display toolkit that enables researchers to realize fully-functional wearable applications which are ready-to-use for real-world field studies. Further, we provide versatile customization options (e.g., surface materials, mounting) and implemented eight applications demonstrating the promising potential (see Figure 1, B1-B8). Finally, we conclude with a discussion for exploring future wearable and personal mobile data visualizations.


**Figure 2: Our prototype consists of (1) a bendable color ePaper display, (2) three membrane potentiometers for touch input, (3) a curved and customizable housing and (4) a wireless multiprotocol, sensor-equipped microcontroller and an EPD driver.**

## 2 E-PAPER TOOLKIT & PROTOTYPE

In the following, we will provide a quick overview of all hardware components (see Figure 2) and introduce our software framework[1].

1 **Display.** Our prototype utilizes an organic active-matrix electrophoretic display (EPD) from Plastic Logic [31] with Advanced Color ePaper (ACeP) technology [13] providing four colors (red, blue, green, yellow) plus black and white. The 2.1" Legio display has a resolution of 240x146 pixels (132ppi), is bendable (r=40mm) and can be interfaced via SPI. A full-color refresh took 15 seconds.

2 **Touch Input & Sensors.** We decided for an explicit pressure touch requiring a small force for triggering actions. Inspired by StrapDisplays [29], we integrated three linear soft membrane potentiometers [47] that we placed behind the display. Besides, built-in sensors [1] extend the input with 9-DoF motion [42, 43] and ambient data (e.g., temperature [7], humidity [40], noise [44], light [8]).

3 **Curved Housing.** To securely enclose the display, we designed a curved case that can be easily 3D-printed and customized with sensory-rich materials such as leather, japan paper, or bindery cloth by (laser) cutting and gluing on custom cover templates. Versatile mounting options allow to wear the display with elastic bands, combine it with (smart) watches or use it as a stand-alone device.

4 **Microcontroller.** Due to its low energy and wireless Bluetooth capabilities, we build on the popular nRF52 SoC series [39]. Therefore, we combine the prototyping-friendly and feature-rich Adafruit Feather nRF52840 Sense [1] with an EPD driver [32]. To power the system up to 24 hours, we velcro-attached a 400mAh LiPo battery under the band which can be charged via USB (see Figure 1, A).

**Connectivity.** The prototype natively supports consumer media keys based on the HID profile. We further built in support for the Apple Notification Center Service (ANCS) [4] to bidirectionally access many kinds of notifications (e.g., call, social, schedule, news, e-mail, health & fitness, location, entertainment) covering the most relevant real-world visualizations on smartwatch faces (cf. [23]).

</> **App Development.** To lower the barrier to entry, all apps are implemented within the Arduino ecosystem [2, 5]. To further simplify the development, we provide a suite of helper classes (e.g., AppManager, AppTemplate, Sensor- and ConnectionManager) as an overarching framework. Visual content is dynamically generated by using the Adafruit GFX [3] and PL_smallEPD [33] library, while Bluetooth services and sensor data can be subscribed on demand.

[1]Detailed instructions and source codes are available online: https://imld.de/epaper/

## 3 IMPLEMENTED EXAMPLE APPLICATIONS

To validate the technical feasibility and demonstrate the potential of our toolkit, we introduce eight example apps (see Figure 1, B1-B8):

**B1** The *Activity App* shows a person's steps by using the inertial system [43] and visualizes a color-coded height profile (ascents in red) using the barometric pressure unit [7]. A blue arrow shows the steps in relation to the daily step goal on a colored progress bar.

**B2** The *Weather App* displays the ambient temperature and humidity using built-in sensors [7, 40]. Further, we started to realize detail views with advanced visualizations (e.g., precipitation curves, conditions) and are working on an integration of real forecast data.

**B3** The *DataVis App* explores visual encoding and interactive visualization techniques (e.g., starplots, scatterplots, charts, graphs) as generic components. We think that such colored widgets could positively impact research on ePaper data visualizations [29, 52].

**B4** The *Watch+Strap App* seamlessly extends (smart) watches with additional, autonomous displays (cf. [29]). Since such applications typically require a strong coupling, we currently implement support for UI streaming [22, 29, 49] to enable distributed, hybrid interfaces.

**B5** The *Notification App* demonstrates how incoming text messages from Apple mobile devices can be natively used for glanceable [6] and ambient usage scenarios using ANCS. Therefore, we realized an app that shows notifications with colorful and expressive emojicons.

**B6** The *Media Controls App* enables body-worn and aesthetic shortcuts for presentations, music player or remote shutter control. Due to its cross-platform implementation using HID profiles, it is possible to connect to any Bluetooth-enabled device without any drivers.

**B7** The *Pattern App* presents an opportunity to turn the body-worn interface into a visual appealing and individually customizable accessory. In this regard, also user-defined inconspicuous interfaces (e.g., hidden progress bars, color-coded events) are possible (cf. [14]).

**B8** The *Work Wear App* builds a basis for discussing new fields of application with domain experts. Therefore, we developed a set of representative work wear visualizations (e.g., hospital staff, construction worker, business analysts) for hands-on ideation sessions.

All apps serve us as a technological as well as conceptual foundation for further research. Additionally, they also could inspire new fields of application beyond wrist-worn devices and will help to quickly bootstrap new projects by building on the set of pre-programmed components (e.g., graphical widgets, sensor & wireless integration).

## 4 DISCUSSION & RESEARCH ROADMAP

While the presented toolkit still has some technical limitations (e.g., refresh rates, available colors, resolution, bend radius), we think that the constant improvement of ePaper technology will provide more advanced EPDs with larger color spaces, faster (partial) refresh options, and even more flexible properties within the next years. As next steps, we plan to move forward in several research directions.

» *Advanced Mobile Visualizations* show promising potential for wearables and smartphones (e.g., [12, 23, 35]). However, ePaper has been primarily used as a monochrome screen (extension) for novel interface assemblies using standard GUI components. Due to the lack of color, only few studies specifically focus on advanced ePaper visualizations. We think that the further investigation of aesthetic, meaningful and color ePaper data visualizations are yet underexplored, but important and promising building blocks for future wearable interfaces. Therefore, we plan to extend our DataVis app and study color-encoded, real-world data visualization in depth.

» *New Form Factors* are driving forces for novel interfaces. While we introduced a curved, wrist-worn wearable as a starting point, we are looking forward to go beyond the wrist and explore new, exciting form factors and flexible hybrid composites. As an example, we see promising potential in embedding EPDs with cutouts into garments to further blend on-clothing displays [11, 20, 24, 28, 34] and AR-attached visualizations [15, 27] into sensory-rich and traditional materials. Moreover, we envision a bright future for color-changing EPDs and films as a *display material* (cf. [46]) for accessories or interior designs using folded, non-planar and polygonal structures.

» *Conducting Field Studies* is a challenging, however, also very valuable method to gain empirical insights and investigate prototypes in their envisioned context of use [21, 38]. We aim to support research beyond the lab and developed a self-contained wearable toolkit. Therefore, we started to test our wrist-worn prototype on ourselves during a five-day hiking tour. We learned that the step counter works equally well as a smartphone, the EPD color slightly changes depending on the environmental temperature and a waterproofed housing is needed for rainy conditions. As a next step, we plan to implement logging and deploy research prototypes to end users to collect usage data and better understand possible design issues.

## 5 CONCLUSION

In summary, we hope to have contributed to the exciting research avenue of novel and innovative display technologies by presenting an accessible research toolkit for easy prototyping with interactive, bendable and color ePaper screens. We described our feature-rich implementation of a curved, functional and colored wearable interface. Based on our design goals of an easy-to-use toolkit with self-contained, real-world functionality, the prototype is designed to enable development within the Arduino ecosystem, to natively support versatile wireless protocols and to be customizable by the user. To demonstrate the technical feasibility and value of the toolkit, we further introduced eight promising real-world applications as a foundation for further research. Finally, we took a glimpse into the future and discussed advanced visualizations, new form factors and field studies with forthcoming wearable applications making use of multi-color and flexible EPDs.

## ACKNOWLEDGMENTS

We would like to thank Robert Poser from Plastic Logic for providing us the electrophoretic displays, the PL_smallEPD base library as well as comprehensive technical support.

This work was supported by Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) as part of Germany's Excellence Strategy EXC 2050/1 - Project ID 390696704 - Cluster of Excellence "Centre for Tactile Internet with Human-in-the-Loop" (CeTI) of Technische Universität Dresden as well as by the DFG grant 389792660 as part of TRR 248 (see https://perspicuous-computing.science).

## REFERENCES

[1] Adafruit. 2021 [Online]. Adafruit Feather nRF52840 Sense. Web: https://www.adafruit.com/product/4516. Accessed: 2021-05-16.

[2] Adafruit. 2021 [Online]. Arduino Core for Adafruit Bluefruit nRF52 Boards. Web: https://github.com/adafruit/Adafruit_nRF52_Arduino. Accessed: 2021-05-16.

[3] Adafruit. 2021 [Online]. GFX Library. Web: https://github.com/adafruit/Adafruit-GFX-Library. Accessed: 2021-05-16.

[4] Apple. 2021 [Online]. Apple Notification Center Service (ANCS) Specification. Web: https://developer.apple.com/library/archive/documentation/CoreBluetooth/Reference/AppleNotificationCenterServiceSpecification/. Accessed: 2021-05-16.

[5] Arduino. 2021 [Online]. Arduino.cc - Open-source electronic prototyping platform. Web: https://www.arduino.cc. Accessed: 2021-05-16.

[6] Tanja Blascheck, Lonni Besançon, Anastasia Bezerianos, Bongshin Lee, and Petra Isenberg. 2019. Glanceable Visualization: Studies of Data Comparison Performance on Smartwatches. *IEEE Transactions on Visualization and Computer Graphics* 25, 1 (2019), 630–640. https://doi.org/10.1109/TVCG.2018.2865142

[7] Bosch Sensortec. 2021 [Online]. BMP280 Sensor - Absolute barometric pressure sensor. Web: https://www.bosch-sensortec.com/products/environmental-sensors/pressure-sensors/bmp280/. Accessed: 2021-05-16.

[8] Broadcom. 2021 [Online]. APDS-9960 - Digital RGB, Ambient Light, Proximity and Gesture Sensor . Web: https://www.broadcom.com/products/optical-sensors/integrated-ambient-light-and-proximity-sensors/apds-9960. Accessed: 2021-06-20.

[9] Jesse Burstyn, Paul Strohmeier, and Roel Vertegaal. 2015. DisplaySkin: Exploring Pose-Aware Displays on a Flexible Electrophoretic Wristband. In *Proceedings of the Ninth International Conference on Tangible, Embedded, and Embodied Interaction* (Stanford, California, USA) *(TEI '15)*. Association for Computing Machinery, New York, NY, USA, 165–172. https://doi.org/10.1145/2677199.2680596

[10] Laura Devendorf, Joanne Lo, Noura Howell, Jung Lin Lee, Nan-Wei Gong, M. Emre Karagozler, Shiho Fukuhara, Ivan Poupyrev, Eric Paulos, and Kimiko Ryokai. 2016. "I Don't Want to Wear a Screen": Probing Perceptions of and Possibilities for Dynamic Displays on Clothing. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (San Jose, California, USA) *(CHI '16)*. Association for Computing Machinery, New York, NY, USA, 6028–6039. https://doi.org/10.1145/2858036.2858192

[11] Christine Dierk, Molly Jane Pearce Nicholas, and Eric Paulos. 2018. AlterWear: Battery-Free Wearable Displays for Opportunistic Interactions *(CHI '18)*. Association for Computing Machinery, New York, NY, USA, 1–11. https://doi.org/10.1145/3173574.3173794

[12] Steven M. Drucker, Danyel Fisher, Ramik Sadana, Jessica Herron, and m.c. schraefel. 2013. TouchViz: A Case Study Comparing Two Interfaces for Data Analytics on Tablets. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Paris, France) *(CHI '13)*. Association for Computing Machinery, New York, NY, USA, 2301–2310. https://doi.org/10.1145/2470654.2481318

[13] E Ink. 2021 [Online]. Advanced Color ePaper (ACeP)- E Ink Gallery Palette. Web: https://www.eink.com/color-technology.html. Accessed: 2021-05-16.

[14] Jutta Fortmann, Erika Root, Susanne Boll, and Wilko Heuten. 2016. Tangible Apps Bracelet: Designing Modular Wrist-Worn Digital Jewellery for Multiple Purposes. In *Proceedings of the 2016 ACM Conference on Designing Interactive Systems* (Brisbane, QLD, Australia) *(DIS '16)*. Association for Computing Machinery, New York, NY, USA, 841–852. https://doi.org/10.1145/2901790.2901838

[15] Anna Fuste and Chris Schmandt. 2018. ARTextiles for Promoting Social Interactions Around Personal Interests. In *Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems* (Montreal QC, Canada) *(CHI EA '18)*. Association for Computing Machinery, New York, NY, USA, 1–6. https://doi.org/10.1145/3170427.3188589

[16] Antonio Gomes, Lahiru Lakmal Priyadarshana, Aaron Visser, Juan Pablo Carrascal, and Roel Vertegaal. 2018. Magicscroll: A Rollable Display Device with Flexible Screen Real Estate and Gestural Input. In *Proceedings of the 20th International Conference on Human-Computer Interaction with Mobile Devices and Services*

(Barcelona, Spain) *(MobileHCI '18)*. Association for Computing Machinery, New York, NY, USA, Article 6, 11 pages. https://doi.org/10.1145/3229434.3229442

[17] Antonio Gomes and Roel Vertegaal. 2015. PaperFold: Evaluating Shape Changes for Viewport Transformations in Foldable Thin-Film Display Devices. In *Proceedings of the Ninth International Conference on Tangible, Embedded, and Embodied Interaction* (Stanford, California, USA) *(TEI '15)*. Association for Computing Machinery, New York, NY, USA, 153–160. https://doi.org/10.1145/2677199.2680572

[18] Tobias Grosse-Puppendahl, Steve Hodges, Nicholas Chen, John Helmes, Stuart Taylor, James Scott, Josh Fromm, and David Sweeney. 2016. Exploring the Design Space for Energy-Harvesting Situated Displays. In *Proceedings of the 29th Annual Symposium on User Interface Software and Technology* (Tokyo, Japan) *(UIST '16)*. Association for Computing Machinery, New York, NY, USA, 41–48. https://doi.org/10.1145/2984511.2984513

[19] Ollie Hanton, Michael Wessely, Stefanie Mueller, Mike Fraser, and Anne Roudaut. 2020. ProtoSpray: Combining 3D Printing and Spraying to Create Interactive Displays with Arbitrary Shapes. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI '20)*. Association for Computing Machinery, New York, NY, USA, 1–13. https://doi.org/10.1145/3313831.3376543

[20] Florian Heller and Kris Luyten. 2019. TaskHerder: A Wearable Minimal Interaction Interface for Mobile and Long-Lived Task Execution. In *Proceedings of the ACM SIGCHI Symposium on Engineering Interactive Computing Systems* (Valencia, Spain) *(EICS '19)*. Association for Computing Machinery, New York, NY, USA, Article 4, 5 pages. https://doi.org/10.1145/3319499.3328226

[21] Niels Henze, Alireza Sahami Shrazi, Albrecht Schmidt, Martin Pielot, and Florian Michahelles. 2013. Empirical Research through Ubiquitous Data Collection. *Computer* 46, 6 (June 2013), 74–76. https://doi.org/10.1109/MC.2013.202

[22] David Holman, Jesse Burstyn, Ryan Brotman, Audrey Younkin, and Roel Vertegaal. 2013. Flexkit: A Rapid Prototyping Platform for Flexible Displays. In *Proceedings of the Adjunct Publication of the 26th Annual ACM Symposium on User Interface Software and Technology* (St. Andrews, Scotland, United Kingdom) *(UIST '13 Adjunct)*. Association for Computing Machinery, New York, NY, USA, 17–18. https://doi.org/10.1145/2508468.2514934

[23] Alaul Islam, Anastasia Bezerianos, Bongshin Lee, Tanja Blascheck, and Petra Isenberg. 2020. Visualizing Information on Watch Faces: A Survey with Smartwatch Users. In *2020 IEEE Visualization Conference (VIS)*. 156–160. https://doi.org/10.1109/VIS47514.2020.00038

[24] Pradthana Jarusriboonchai, Hong Li, Emmi Harjuniemi, Heiko Müller, and Jonna Häkkilä. 2020. Always with Me: Exploring Wearable Displays as a Lightweight Intimate Communication Channel. In *Proceedings of the Fourteenth International Conference on Tangible, Embedded, and Embodied Interaction* (Sydney NSW, Australia) *(TEI '20)*. Association for Computing Machinery, New York, NY, USA, 771–783. https://doi.org/10.1145/3374920.3375011

[25] Yuhua Jin, Isabel Qamar, Michael Wessely, Aradhana Adhikari, Katarina Bulovic, Parinya Punpongsanon, and Stefanie Mueller. 2019. Photo-Chromeleon: Re-Programmable Multi-Color Textures Using Photochromic Dyes. In *Proceedings of the 32nd Annual ACM Symposium on User Interface Software and Technology* (New Orleans, LA, USA) *(UIST '19)*. Association for Computing Machinery, New York, NY, USA, 701–712. https://doi.org/10.1145/3332165.3347905

[26] Konstantin Klamka and Raimund Dachselt. 2017. IllumiPaper: Illuminated Interactive Paper. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (Denver, Colorado, USA) *(CHI '17)*. Association for Computing Machinery, New York, NY, USA, 5605–5618. https://doi.org/10.1145/3025453.3025525

[27] Konstantin Klamka and Raimund Dachselt. 2018. ARCord: Visually Augmented Interactive Cords for Mobile Interaction. In *Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems* (Montreal QC, Canada) *(CHI EA '18)*. Association for Computing Machinery, New York, NY, USA, 1–6. https://doi.org/10.1145/3170427.3188456

[28] Konstantin Klamka, Raimund Dachselt, and Jürgen Steimle. 2020. Rapid Iron-On User Interfaces: Hands-on Fabrication of Interactive Textile Prototypes. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI '20)*. Association for Computing Machinery, New York, NY, USA, 1–14. https://doi.org/10.1145/3313831.3376220

[29] Konstantin Klamka, Tom Horak, and Raimund Dachselt. 2020. Watch+Strap: Extending Smartwatches with Interactive StrapDisplays. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI '20)*. Association for Computing Machinery, New York, NY, USA, 1–15. https://doi.org/10.1145/3313831.3376199

[30] Byron Lahey, Audrey Girouard, Winslow Burleson, and Roel Vertegaal. 2011. PaperPhone: Understanding the Use of Bend Gestures in Mobile Devices with Flexible Electronic Paper Displays. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Vancouver, BC, Canada) *(CHI '11)*. Association for Computing Machinery, New York, NY, USA, 1303–1312. https://doi.org/10.1145/1978942.1979136

[31] Plastic Logic. 2021 [Online]. 2.1" Legio Colour Display. Web: https://www.plasticlogic.com/?product=2-1-legio-colour-display. Accessed: 2021-06-20.

[32] Plastic Logic. 2021 [Online]. Feather Legio™ / Lectum™ Shield. Web: https://www.plasticlogic.com/?product=feather-nrf52840-express-for-2-1-legio-colour-display. Accessed: 2021-06-20.

[33] Plastic Logic. 2021 [Online]. PL_smallEPD Arduino Library. Web: https://github.com/plasticlogic/PL_smallEPD. Accessed: 2021-06-20.

[34] Matthew Mauriello, Michael Gubbels, and Jon E. Froehlich. 2014. Social Fabric Fitness: The Design and Evaluation of Wearable E-Textile Displays to Support Group Running. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Toronto, Ontario, Canada) *(CHI '14)*. Association for Computing Machinery, New York, NY, USA, 2833–2842. https://doi.org/10.1145/2556288.2557299

[35] Ali Neshati, Bradley Rey, Ahmed Shariff Mohommed Faleel, Sandra Bardot, Celine Latulipe, and Pourang Irani. 2021. BezelGlide: Interacting with Graphs on Smartwatches with Minimal Screen Occlusion. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems* (Yokohama, Japan) *(CHI '21)*. Association for Computing Machinery, New York, NY, USA, Article 501, 13 pages. https://doi.org/10.1145/3411764.3445201

[36] Simon Olberding, Michael Wessely, and Jürgen Steimle. 2014. PrintScreen: Fabricating Highly Customizable Thin-Film Touch-Displays *(UIST '14)*. Association for Computing Machinery, New York, NY, USA, 281–290. https://doi.org/10.1145/2642918.2647413

[37] Christian Rendl, David Kim, Patrick Parzer, Sean Fanello, Martin Zirkl, Gregor Scheipl, Michael Haller, and Shahram Izadi. 2016. FlexCase: Enhancing Mobile Interaction with a Flexible Sensing and Display Cover. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (San Jose, California, USA) *(CHI '16)*. Association for Computing Machinery, New York, NY, USA, 5138–5150. https://doi.org/10.1145/2858036.2858314

[38] Albrecht Schmidt, Florian Alt, and Ville Mäkelä. 2021. Evaluation in Human-Computer Interaction – Beyond Lab Studies. In *Extended Abstracts of the 2021 CHI Conference on Human Factors in Computing Systems* (Yokohama, Japan) *(CHI EA '21)*. Association for Computing Machinery, New York, NY, USA, Article 142, 4 pages. https://doi.org/10.1145/3411763.3445022

[39] Nordic Semiconductor. 2021 [Online]. nRF52840 - System-on-Chip. Web: https://www.nordicsemi.com/Products/Low-power-short-range-wireless/nRF52840. Accessed: 2021-05-16.

[40] Sensirion. 2021 [Online]. Digital Humidity Sensor SHT31. Web: https://www.sensirion.com/en/environmental-sensors/humidity-sensors/digital-humidity-sensors-for-various-applications/. Accessed: 2021-06-20.

[41] Sony. 2019 [Online]. Sony FES Watch U - ePaper Fashion Watch. Web: https://www.sony.co.uk/electronics/fes-watch-u-collection/fes-wa1. Accessed: 2019-12-12.

[42] STMicroelectronics. 2021 [Online]. LIS3MDL - Digital Output Magnetic Sensor. Web: https://www.st.com/en/mems-and-sensors/lis3mdl.html. Accessed: 2021-06-20.

[43] STMicroelectronics. 2021 [Online]. LSM6DS33 - iNEMO Inertial Module. Web: https://www.st.com/en/mems-and-sensors/lsm6ds33.html. Accessed: 2021-05-16.

[44] STMicroelectronics. 2021 [Online]. MP34DT01-M - Digital MEMS microphone. Web: https://www.st.com/en/audio-ics/mp34dt01-m.html. Accessed: 2021-06-20.

[45] Paul Strohmeier, Jesse Burstyn, and Roel Vertegaal. 2015. Effects of Display Sizes on a Scrolling Task Using a Cylindrical Smartwatch. In *Proceedings of the 17th International Conference on Human-Computer Interaction with Mobile Devices and Services Adjunct* (Copenhagen, Denmark) *(MobileHCI '15)*. Association for Computing Machinery, New York, NY, USA, 846–853. https://doi.org/10.1145/2786567.2793710

[46] David Sweeney, Nicholas Chen, Steve Hodges, and Tobias Grosse-Puppendahl. 2016. Displays as a Material: A Route to Making Displays More Pervasive. *IEEE Pervasive Computing* 15, 3 (2016), 77–82. https://doi.org/10.1109/MPRV.2016.56

[47] Spectra Symbol. 2021 [Online]. Linear ThinPot, 50mm - TSP-L-0050-103-3%-ST. Web: https://www.spectrasymbol.com/product/thinpot/. Accessed: 2021-05-16.

[48] Aneesh P. Tarun, Peng Wang, Audrey Girouard, Paul Strohmeier, Derek Reilly, and Roel Vertegaal. 2013. PaperTab: An Electronic Paper Computer with Multiple Large Flexible Electrophoretic Displays. In *CHI '13 Extended Abstracts on Human Factors in Computing Systems* (Paris, France) *(CHI EA '13)*. Association for Computing Machinery, New York, NY, USA, 3131–3134. https://doi.org/10.1145/2468356.2479628

[49] Ulrich von Zadow, Wolfgang Büschel, Ricardo Langner, and Raimund Dachselt. 2014. SleeD: Using a Sleeve Display to Interact with Touch-Sensitive Display Walls. In *Proceedings of the Ninth ACM International Conference on Interactive Tabletops and Surfaces* (Dresden, Germany) *(ITS '14)*. Association for Computing Machinery, New York, NY, USA, 129–138. https://doi.org/10.1145/2669485.2669507

[50] Dirk Wenig, Florian Heller, and Johannes Schöning. 2016. StrapMaps: Bringing Map-Based Navigation to the Straps of Bags. In *Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing: Adjunct* (Heidelberg, Germany) *(UbiComp '16)*. Association for Computing Machinery, New York, NY, USA, 225–228. https://doi.org/10.1145/2968219.2993411

[51] Michael Wessely, Yuhua Jin, Cattalyya Nuengsigkapian, Aleksei Kashapov, Isabel P. S. Qamar, Dzmitry Tsetserukou, and Stefanie Mueller. 2021. ChromoUpdate: Fast Design Iteration of Photochromic Color Textures Using Grayscale

Previews and Local Color Updates. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems* (Yokohama, Japan) *(CHI '21)*. Association for Computing Machinery, New York, NY, USA, Article 666, 13 pages. https://doi.org/10.1145/3411764.3445391

[52] Yuanyang Zhong, Tobias Isenberg, and Petra Isenberg. 2020. Black-and-White Textures for Visualization on E-ink Displays. Posters of IEEE Visualization. https://hal.inria.fr/hal-02944212 Poster.