Sketching On-Body Interactions using Piezo-Resistive Kinesiology Tape

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ABSTRACT

Skin is personal and sensitive. As a result, design and placement of on-body physical interfaces need to be well thought out. One way of "getting the design right" is to quickly sketch a multitude of designs to be modified, adjusted and elaborated on. To date, on-body rapid prototyping methods do not afford these "quick-and-dirty" design processes. We propose using piezo-resistive kinesiology tape as a low-cost and versatile resource for sketching functional on-skin interfaces. Our method uses pretreated kinesiology tape, which is made piezo-resistive through polymerization, and serves as touch, pressure and stretch sensor. We illustrate ketching techniques with both pretreated and untreated tape for iterative design of on-skin interfaces. In addition, we contribute a set of sensor primitives that facilitate various input modalities for creating interactive sketches.

CCS CONCEPTS

• **Human-centered computing** → **Human computer interaction (HCI)**; • **Hardware** → *Sensors and actuators.*

KEYWORDS

Rapid prototyping; Fabrication; Epidermal devices; On-Body interactions; Wearables; E-textile; Sensors

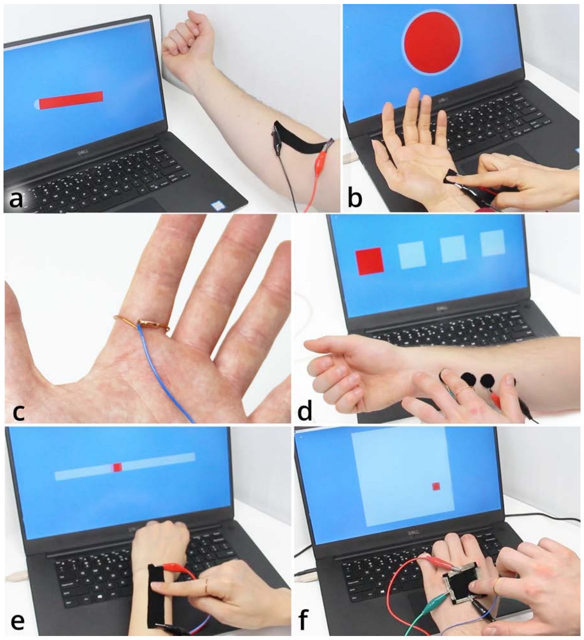

Figure 1: Kinesiology tape can be turned piezo-resistive through polymerization and positioned on the body to sense motion (a) or pressure (b). Using a simple conductive ring on the interacting finger (c) enables creating sensors for sensing touch (d), linear positions (e), and gestures (f).

1 INTRODUCTION

On-skin interaction [2, 31] is gaining momentum in HCI research. Research efforts aim at a better understanding of design requirements specific to the human body [39], and at leveraging the body's advantages and idiosyncrasies [3, 32, 40]. In addition, technologies which enable the skin to be used as interface, for example through touch [13, 14, 21, 38, 42, 44], or deformation [26], are comprehensively researched. By contrast, direct, physical prototyping of on-body systems is only sparsely covered. Notable exceptions include Kao et al.'s participatory design sessions on DuoSkin [21], and methods for directly creating and printing designs on the body [20]. Gannon et al. also explored how one might use the body, when designing passive objects for the body [10]. As suggested by a study participant "It makes sense that

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AHs '20, March 16–17, 2020, Kaiserslautern, Germany

ACM ISBN 978-1-4503-7603-7/20/03.
https://doi.org/10.1145/3384657.3384774

if you're designing something to wear on your body, you should be-able to literally design it on your body." [10]

We expand upon this space by providing a method of physical prototyping which supports the rapid creation of "quick and dirty" and *electrically functional* prototypes *on the body*. Using resistive kinesiology tape, designers and HCI practitioners can, within minutes, iterate through multiple designs working with and on the body. The suggested design method allows adding haptic features, can be deployed throughout the body, and supports multiple sensing modalities.

We propose using piezo-resistive kinesiology tape for creating interactive skin patches to enable rapid collaborative prototyping of on-skin input devices. Kinesiology tape is readily available at low cost. If prepared in advance, off-the shelf kinesiology tape can be made piezo-resistive in large batches [18]. Once this is done, kinesiology tape has a series of beneficial properties, in addition to being piezo-resistive: It comes coated with a bio-compatible glue layer for applying it to the body, its elasticity is tuned to complement that of the body, and the tape form factor makes it compatible with a body's complex geometries. It supports low-fidelity prototyping as it can be cut with scissors, and easily modified and adjusted.

In this paper, we start by briefly outlining how to create piezo-resistive tape based on existing literature. We then discuss the main contributions of this paper, which are (1) the prototyping workflow for augmenting various body areas of different size, geometry and deformability with patches made of piezo-resistive tape, as well as (2) a series of sensor primitives which are supported by this workflow (Figure 1).

2 RELATED WORK

Sketching is a method of *low fidelity prototyping* allowing exploration of a design space before committing to a single idea or concept [12]. Sketching transcends disciplines, and has a rich tradition in both design and interaction design [4]. In the context of on-skin interaction, the interface becomes part of the user's skin, of their personal and sensitive spaces. The challenges of designing on-skin interactions are not only of technical nature, but also comprise important social and experiential challenges. As a consequence, early prototyping and rapid exploration and iteration become vital. In this context, the use of sketching tools – including but also beyond traditional pen and paper – becomes increasingly important [16].

Prior work demonstrates the value of sketching and low-fidelity (or "quick-and-dirty") prototypes for reflection on design opportunities for wearables [23], to facilitate idea generation [8, 23], or simulate the locations of displays [7]. Ten Bhömer et al. highlight that "concepts should be tried on the body from an early stage" and demonstrate how textile draped on the body can be used to sketch and iterate concepts in 3D [34]. Nevertheless, the body of work exploring rapid live sketching of interactive on-body user interfaces is limited. This is surprising, as in fashion design there is a long tradition of iterating and testing directly on the body, for instance in draping, or on-body pattern making [9, 36]. This tradition is used in work by Strohmeier et al. who demonstrate textile touch and pressure sensors, that can be pinned to clothes, to explore placement, before finally being ironed or sewn in place [33]. Other systems for supporting rapid prototyping in textiles include rapid iron-on interface [22] and Wearable Bits [19].

In contrast, epidermal devices are most commonly designed digitally, and then fabricated. Prior work has, for instance, contributed a digital design tool for shape-customized multi-touch sensors for the body [25] or provide guidelines for using digital design for epidermal bio-sensing [24]. In contrast, Gannon et al.'s work on ExoSkin discusses off-body and on-body fabrication workflows including printing (passive) artifacts directly on the body [11]. Rapid on-skin prototyping of electronic interfaces is addressed by DuoSkin [21], where the authors demonstrate a customizable fabrication technique using gold leaf and stencils. While these works illustrate the growing interest towards rapid prototyping directly on the body, the suggested workflows significantly differ from the aforementioned low-fidelity, or "quick-and-dirty" prototyping techniques: they require some certainty, effort and refinement. In consequence, they are all excellent techniques for later design stages, but do not afford what is essential to sketching: the creation of a multitude of rough idea representations to modify, extend, and - maybe - even throw away and re-sketch (c.f., Greenberg et al. [12]). We expand upon those prior methods by contributing an on-skin prototyping process using piezo-resistive kinesiology tape that allows for "quick-and-dirty" exploration and iteration of on-skin input devices.

Currently, interaction with on-skin interfaces is typically based on capacitive touch sensing [25]. Only few epidermal interfaces leverage piezo-resistive sensing properties [38]. In contrast, piezo-resistive fabric is more commonly employed in the context of electronic textiles, often to implement the popular pressure sensor matrix design [6, 28, 29]. Piezo-resistive flexible materials have also been explored using linear sensors [17] or mesh-structures which wrap around objects [15]. Holman highlights the utility of the tape-form factor [5, 17], as it can be wrapped around objects to create volumetric sensors. The low-fidelity prototyping method we suggest also leverages this property of tape. To further support rapid low-effort prototyping, we simplify previous sensor designs by treating the piezo-resistive tape areas as signal emitters. By capturing the signal on the finger that touches the sensor, a variety of sensor primitives

Figure 2: In contrast to other prototyping techniques, kinesiology tape allows to directly sketch on the body. Designs (a) can be rapidly modified, e.g., cut (b-c), and repositioned (d-e) to try out various scenarios.

become possible (Figure 1 and Section 4). As a result, the complex mechanical stacking of layers which other types of resistive sensors require (e.g. [6, 29, 37]) is not necessary, and the prototyping process is simplified.

3 PREPERATION

Before rapidly prototyping, various preperations mus be made: Piezo-resistive kinesiology tape can be created through polymerization with pyrrole [1, 43]. Honnet et al. [18] present a simple workflow for polymerization in a DIY context: Kinesiology tape is submerged and soaked in a pyrrole solution (25 ml pyrrole to 1000 ml water) for 10 minutes. 10 mg Iron (III) Chloride (Hexahydrate) chloride is added per liter of water, and the material is mixed for ~ 45 minutes until polymerization is completed [18]. Polymerized kinesiology tape can be prepared ahead, and in large batches. Next, we discuss how to use it for rapid sketching. In addition to off-the-shelf (non resistive) and pretreated (piezo-resistive) tape, basic tools such as scissors, crocodile clamps, resistors in the $k\Omega$ to $M\Omega$ range, and microcontrollers are required.

4 DESIGN PROCESS

Sketching Interactions

Using kinesiology tape instead of commonly used pen-and-paper, offers unique benefits for sketching on-body interfaces. The practice of applying patches of kinesiology tape to body parts is well-established in athletic and therapeutic contexts, and allows to appropriate a rich repertoire of attachment methods. Made of skin-compatible materials that readily adhere to skin, kinesiology tape offers a very flexible form factor, which is compatible with various body locations, body movement, and forms of interaction. In the following, we present a set of basic interactions for sketching functional on-body user interfaces.

Cutting & Applying. Unlike prototyping processes in which much of the design happens in CAD software [27], working with sensing patches is a very physical process – directly on, with, and around the body. Physical interaction with materials on and around the body offers benefits for rapid concept creation and iteration. Cutting the tape to the desired length or shape and applying it to the body can be understood as a key element to designing. For instance, one might directly take measurements on the body using the tape ("how long should this sensor be?"), cut it to the appropriate length, and apply it, rather than taking the detour over digital design methods (Figure 2). A multitude of design alternatives can be rapidly fabricated by varying length, shape, and location of an individual patch, or by arranging, juxtaposing or layering multiple patches.

Exploring Shape & Texture. Kinesiology tape is soft and deformable, which allows for improvisation when designing the shape of a sensing patch. The tape's form factor itself supports various interface shapes, ranging from simple buttons or linear sliders to advanced geometries, such as a spiral-shaped sensor wrapped around a cylindrical body part (e.g., a finger). While applying the patch, the elasticity of the kinesiology tape allows to adjust and re-adjust shape and placement (Figure 2). This can be used to make the shape conform to the shape of the body, without a need to take exact measures beforehand. Similarly one can experiment with texture while applying the tape, for example by adding creases, ridges and folds for haptic feedback. Figure 3a shows a sensing patch which originally was straight, but then laid out in a curved shape to fit the body while being applied. Figure 3b shows a patch which was cut and applied in circular form.

Rapidly Iterating Designs. Kinesiology tape maintains some of its adhesive capacity, even after having been applied and removed. This makes it easy to perform rapid design iterations. For instance, one can slightly adjust the shape of a sensing patch multiple times, by lifting and re-applying parts of it, move it to another body location, or even reconfigure it by cutting it and re-applying it in an altered arrangement (Figure 2).

Combination with Non Conductive Tape. Non conductive tape is also an excellent tool for prototyping on-skin interfaces. We used it to create haptic guides from combinations of resistive and non-resistive kinesiology tape. For instance, piezo-resistive tape can be rolled up to form a ridge, and applied using a cutout in a piece of non-resistive tape (Figure 3c). Similarly, non-resistive tape can be utilized to create visual guides (Figure 3d), or attach further electronic elements, e.g., buttons, switches or microcontrollers to the body

Figure 3: Kinesiology tape allows for a large variety of on-skin placements, including areas with non-uniform curvature, such as around the neck (a) or bones (b). The combination of non-resistive (blue) and pretreated (piezo-resistive, black) kinesiology tape allows using ridges and folds (c), partitions (d), and electronic components (e).

(Figure 3e). In summary, these techniques allow to comprehensively sketch out the envisioned concepts for on-skin interaction to be iterated on.

Sensing Modalities

In this section we present five sensor primitives which can be implemented using piezo-resistive kinesiology tape. Each of the presented sensors can work on their own, but they are designed so that they can be used concurrently. By this we mean, for example, a directional slider can also be used as a pressure sensor, without requiring changes in the wiring. This allows designers to change functionality of sensing elements after they have been deployed.

A further consideration of these designs is the relatively high resistance of the kinesiology tape, both in absolute terms and relative to the resistance of the skin. This makes traditional sensing methods such as capacitive touch difficult to use. Instead we suggest that the finger which performs the touch is integrated in the sensing circuit and used to measure voltage: For touch sensors (Figure 1d), directional slider (Figure 1e), and gesture sensor (Figure 1f), the user wears a copper ring on the active hand, and the voltage of the finger is measured using that copper ring (Figure 1c). This principle not only helps dealing with many problems introduced by the high resistance, it also allows us to reduce the mechanical complexity of the directional slider and gesture sensors.

All code used for these examples, as well as additional information regarding polymerization) is available at https://counterchemists.github.io/.

Touch Sensors [Video Figure 1:33]. We sense touch with exposed conductive patches, connected to digital outputs of a microcontroller. The digital pin connected to the sensor is grounded by default. All touch sensors are sequentially pulled high and the voltage is measured at the finger performing the touch. Touch is detected when a touch sensor is pulled high, and the voltage measured at the touching finger reacts correspondingly. In Figure 4a we can detect that the user is touching the sensing patch #2, as an increase in voltage is measured when that patch is pulled high (t2 and t5). When using directional sliders or gesture sensors, this method can be used to identify which sensor is being touched.

Directional Slider [Video Figure 0:45]. Sensing swipes and sliding gestures with piezo-resistive materials usually involves designs with multiple layers of materials. For example, the linear resistive touch sensor by Holman consists of a resistive layer, a spacing layer and a conductive layer [17]. The complexity of such sensors can be reduced by sampling the voltage at the finger that is touching. Integrating the touching finger into the sensing circuit in this way enables sensing of touch positions with a single-layer design. This allows us to directly use single-layer kinesiology tape for realizing swipe and slide input with customized length.

Connecting one side of the sensing patch to GND and the other to V+ creates a linear voltage gradient (Figure 4b). If the finger touching the patch is connected to an analog input pin, the voltage measured at the finger varies in proportion to its position along the patch which allows to infer its position. By measuring the minimum and maximum voltage at the far edges of the sensor, the slider can also be used as a position sensor. Changes in voltage map linearly to changes in distance: In Figure 4b the voltage differential $d1$ has the same ratio to the voltage differential $d1+d2$, as the distance of the finger to ground has to the entire length of the slider. If the directional slider is wide, one should ensure that the entire edge perpendicular to the direction of the gradient is of high conductance. This can be achieved by sewing a strip of conductive fabric to it, or connecting it to copper tape.

Gesture Sensor [Video Figure 1:19]. Traditional 4-wire touchscreens use rigid multi-layer designs which do not work if deformed [30]. Pressure sensor matrix designs can be bent, however, they require multiple layers, and are not easily reconfigurable [6, 45]. By, integrating the touching finger into the circuit, and sampling the voltage at its skin, and by alternatively applying a horizontal and vertical voltage gradient to the patch, a gesture sensor can be implemented using a single sensing patch:

All four sides of a gesture patch are connected to digital pins. To achieve a uniform voltage on all sides, a strip of conductive fabric can be sewn to each edge. Initially, (t1 Figure 4c) the left side is pulled low, while the right hand side is pulled high. Top and bottom pins are either in high-impedance state, or better still, disconnected using relays. Measuring the voltage at the finger provides a first coordinate

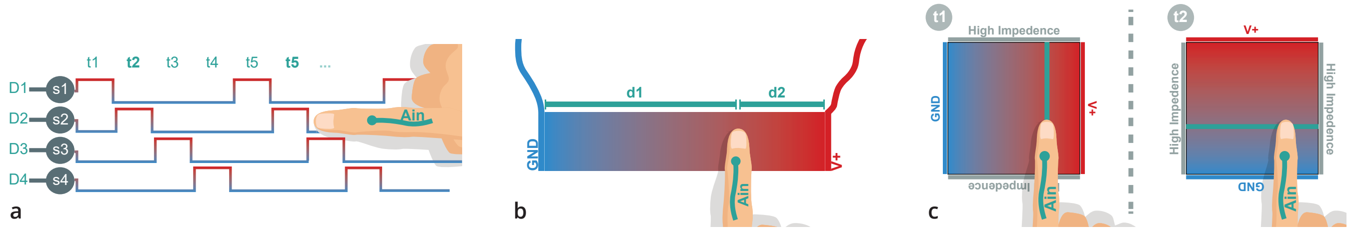

Figure 4: Electrical principles used for touch sensing (a), linear position sensing (b), and gesture sensing (c).

of a 2D gesture. In a second step (t2) The bottom and top sides are pulled low and high, while the left and right sides are removed from the circuit. Measuring the voltage at the finger provides a second coordinate. The resulting sensor provides an x and y coordinate output which can be used in basic gesture detection algorithms such as the $1 recognizer [41].

The gesture sensor, as implemented here, is not a true 2D touch-pad. The conductive edges distort the voltage gradient, moving the measured touch-point away from the centre. A simple calibration scheme can be implemented that remaps the values using a look-up table, however the sensing resolution will not be uniform.

Stretch and Pressure Sensing [Video Figure 0:55]. As the sensing patches are piezo-resistive, they can also be used for regular piezo-resistive sensing. Changes in pressure and stretch result in a change in resistance through the material, which can be sampled using a voltage divider. Using kinesiology tape, designers can place pressure and stretch sensing patches anywhere on the body (Figure 1a and 1b). Using stretch-sensitive patches designers can sense deep inhaling, or movement of joints (Figure 1b). Using pressure-sensitive patches, designers can explore the different experience of pressure on hard surfaces such as knuckles or softer areas such as cheeks or thighs. Anecdotally, the pressure sensor performed well for relatively high pressure input (~5 to ~15 newton). For gentle taps, we suggest using touch-sensors instead.

While most pressure sensor designs place a piezo-resistive fabric in between two conductive materials for perpendicular sensing, the piezo-resistive kinesiology tape allows transverse measuring of pressure. By sensing pressure transversely, the mechanical complexity of the sensor is significantly reduced.

Opportunities and Limitations. If multiple directional sliders or gesture sensors are placed on a user, the measured values would not identify which one is being touched. This can be addressed by initially using all sensors as touch-sensors. Then, once the sensor has identified that it is being touched, the function can be – in software – switched to whatever is required. This is possible because most microcontroller pins can internally be configured for various behaviors, previous work has leveraged this for creating so called *hybrid sensors* [33]. By rapidly switching between pin-configurations, a single sensor could act as touch sensor, pressure sensor, directional slider, and gesture sensor at once.

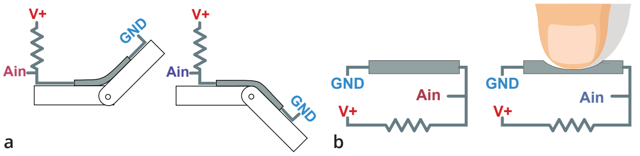

Figure 5: Voltage divider circuits for bend (a) and pressure (b) sensing.

However, the sensors, as presented, also have clear constraints. For one, the preperation method, as described by Honnet et al. [18] results in tape with resistances in the $M\Omega$ range. This is a drawback as it is within the same range of resistance as human skin, which can cause parasitic resistance. The other consequence is that, for typical microcontrollers, pull-up resistors and high-impedance states are of comparatively low resistance, which can cause unexpected behavior due to parasitic resistance.

The issue of high-resistance of the tape might be addressed with chemical doping, by adding additional iron(III) chloride or p-toluenesulfonic acid during the polymerization process to increase conductivity. Problems with the relatively low resistance of pins in high-z state and pull-up resistors can also be addressed by controlling signals via relay-boards. Finally, by treating signals with some care, and applying basic filtering (see code examples at https://counterchemists.github.io/) results can be optimized.

5 CONCLUSION

We presented a sketching method for functional on-skin interfaces. Off-the-shelf kinesiology tape becomes interactive when it is turned piezo-resistive through polymerization. This allows rapid experimentation with on-body input. We suggest kinesiology tape as a tool for sketching on and around the body for various reasons: It draws strength from its directness as shapes, sizes and positions can be determined and adjusted immediately on the body. The form factor matches the need for a thin and flexible material that can approximate state-of-the-art epidermal input devices [25]. As highlighted by prior work [5, 17, 37], the tape form factor also affords to be cut to any length, and attached to curved or organic shapes such as the human body. Using tape, all these factors come together, enabling "getting the design right" by quickly sketching out a multitude of potential designs to be modified, adjusted and explored.

While we envisioned our work to fill in the gap of a "quick-and-dirty" prototyping method for on-skin interactions, the presented sketching techniques and sensor primitives can also be employed in other areas, where deformable input, touch, pressure, or stretch sensors might be required, for instance in textile interfaces [35]. Our contribution is an enabling technology, and we hope to see it used in workshops and participatory design sessions in the future. Code examples for implementing sensors, and documentation of the polymerization process can be found at https://counterchemists.github.io/.

6 ACKNOWLEDGEMENTS

This work was supported by the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation program (grant agreement No. 714797 ERC Starting Grant InteractiveSkin).

REFERENCES

[1] A. C. Baptista, I. Ropio, B. Romba, J. P. Nobre, C. Henriques, J. C. Silva, J. I. Martins, J. P. Borges, and I. Ferreira. 2018. Cellulose-based electrospun fibers functionalized with polypyrrole and polyaniline for fully organic batteries. *Journal of Materials Chemistry A* 6, 1 (dec 2018), 256–265. https://doi.org/10.1039/C7TA06457H

[2] Joanna Bergström and Kasper Hornbæk. 2019. Human-Computer Interaction on the Skin. *ACM Comput. Surv.* 52, 4, Article Article 77 (Aug. 2019), 14 pages. https://doi.org/10.1145/3332166

[3] Joanna Bergstrom-Lehtovirta, Sebastian Boring, and Kasper Hornbæk. 2017. Placing and Recalling Virtual Items on the Skin. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems (CHI '17)*. Association for Computing Machinery, New York, NY, USA, 1497–1507. https://doi.org/10.1145/3025453.3026030

[4] Bill Buxton. 2010. *Sketching user experiences: getting the design right and the right design.* Morgan kaufmann.

[5] Artem Dementyev, Hsin-Liu (Cindy) Kao, and Joseph A. Paradiso. 2015. SensorTape: Modular and Programmable 3D-Aware Dense Sensor Network on a Tape. In *Proceedings of the 28th Annual ACM Symposium on User Interface Software & Technology (UIST '15)*. Association for Computing Machinery, New York, NY, USA. https://doi.org/10.1145/2807442.2807507

[6] Maurin Donneaud, Cedric Honnet, and Paul Strohmeier. 2017. Designing a Multi-Touch eTextile for Music Performances. In *Proceedings of the International Conference on New Interfaces for Musical Expression.* 7–12. http://www.nime.org/proceedings/2017/nime2017{_}paper0002.pdf

[7] Felix Anand Epp. 2019. Expressive Wearables: Practices-Oriented Codesign for New Forms of Social Mobile Technology. *International Journal of Mobile Human Computer Interaction (IJMHCI)* 11, 4 (2019), 1–15.

[8] 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 (DIS '16)*. Association for Computing Machinery, New York, NY, USA, 841–852. https://doi.org/10.1145/2901790.2901838

[9] Rachel Freire, Paul Strohmeier, Cedric Honnet, Jarrod Knibbe, and Sophia Brueckner. 2018. Designing ETextiles for the Body: Shape, Volume & Motion. In *Proceedings of the Twelfth International Conference on Tangible, Embedded, and Embodied Interaction (TEI '18)*. Association for Computing Machinery, New York, NY, USA, 728–731. https://doi.org/10.1145/3173225.3173331

[10] Madeline Gannon, Tovi Grossman, and George Fitzmaurice. 2015. Tactum: A Skin-Centric Approach to Digital Design and Fabrication. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems (CHI '15)*. Association for Computing Machinery, New York, NY, USA, 1779–1788. https://doi.org/10.1145/2702123.2702581

[11] Madeline Gannon, Tovi Grossman, and George Fitzmaurice. 2016. ExoSkin: On-Body Fabrication. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI '16)*. Association for Computing Machinery, New York, NY, USA, 5996–6007. https://doi.org/10.1145/2858036.2858576

[12] Saul Greenberg, Sheelagh Carpendale, Nicolai Marquardt, and Bill Buxton. 2011. *Sketching user experiences: The workbook.* Elsevier.

[13] Chris Harrison, Hrvoje Benko, and Andrew D. Wilson. 2011. OmniTouch: Wearable Multitouch Interaction Everywhere. In *Proceedings of the 24th Annual ACM Symposium on User Interface Software and Technology (UIST '11)*. Association for Computing Machinery, New York, NY, USA, 441–450. https://doi.org/10.1145/2047196.2047255

[14] Chris Harrison, Desney Tan, and Dan Morris. 2010. Skinput: Appropriating the Body as an Input Surface. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '10)*. Association for Computing Machinery, New York, NY, USA, 453–462. https://doi.org/10.1145/1753326.1753394

[15] David Holman, Nicholas Fellion, and Roel Vertegaal. 2014. Sensing Touch Using Resistive Graphs. In *Proceedings of the 2014 Conference on Designing Interactive Systems (DIS '14)*. Association for Computing Machinery, New York, NY, USA, 195–198. https://doi.org/10.1145/2598510.2598552

[16] David Holman, Audrey Girouard, Hrvoje Benko, and Roel Vertegaal. 2013. The Design of Organic User Interfaces: Shape, Sketching and Hypercontext. *Interacting with Computers* 25, 2 (03 2013), 133–142. https://doi.org/10.1093/iwc/iws018 arXiv:https://academic.oup.com/iwc/article-pdf/25/2/133/2300729/iws018.pdf

[17] David Holman and Roel Vertegaal. 2011. TactileTape: Low-Cost Touch Sensing on Curved Surfaces. In *Proceedings of the 24th Annual ACM Symposium Adjunct on User Interface Software and Technology (UIST '11 Adjunct)*. Association for Computing Machinery, New York, NY, USA, 17–18. https://doi.org/10.1145/2046396.2046406

[18] Cedric Honnet, Hannah Perner-wilson, Marc Teyssier, Bruno Fruchard, Juergen Steimle, Ana C Baptista, and Paul Strohmeier. 2020. PolySense: Augmenting Textiles with Electrical Functionality using In-Situ Polymerization. In *Proc. CHI.*

[19] Lee Jones, Sara Nabil, Amanda McLeod, and Audrey Girouard. 2020. Wearable Bits: Scaffolding Creativity with a Prototyping Toolkit for Wearable E-Textiles. In *Proceedings of the Fourteenth International Conference on Tangible, Embedded, and Embodied Interaction (TEI '20)*. Association for Computing Machinery, New York, NY, USA, 165–177. https://doi.org/10.1145/3374920.3374954

[20] Hsin-Liu Cindy Kao, Abdelkareem Bedri, and Kent Lyons. 2018. SkinWire: Fabricating a Self-Contained On-Skin PCB for the Hand. *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.* 2, 3, Article Article 116 (Sept. 2018), 23 pages. https://doi.org/10.1145/3264926

[21] Hsin-Liu Cindy Kao, Christian Holz, Asta Roseway, Andres Calvo, and Chris Schmandt. 2016. DuoSkin: rapidly prototyping on-skin user interfaces using skin-friendly materials. In *Proceedings of the 2016 ACM International Symposium on Wearable Computers.* ACM, 16–23.

[22] Konstantin Klamka, Raimund Dachselt, and Jürgen Steimle. 2020. Rapid Iron-On User Interfaces: Hands-on Fabrication of Interactive Textile Prototypes. In *Proc. CHI '20*. 1–14.

[23] Marion Koelle, Katrin Wolf, and Susanne Boll. 2018. Beyond LED Status Lights - Design Requirements of Privacy Notices for Body-Worn Cameras. In *Proceedings of the Twelfth International Conference on Tangible, Embedded, and Embodied Interaction (TEI '18)*. Association for Computing Machinery, New York, NY, USA, 177–187. https://doi.org/10.1145/3173225.3173234

[24] Aditya Shekhar Nittala, Arshad Khan, Klaus Kruttwig, Tobias Kraus, and Jürgen Steimle. 2020. PhysioSkin: Rapid Fabrication of Skin-Conformal Physiological Interfaces. In *Proic. CHI '20*. https://doi.org/10.1145/3313831.3376366

[25] Aditya Shekhar Nittala, Anusha Withana, Narjes Pourjafarian, and Jürgen Steimle. 2018. Multi-Touch Skin: A Thin and Flexible Multi-Touch Sensor for On-Skin Input. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (CHI '18)*. Association for Computing Machinery, New York, NY, USA, Article Paper 33, 12 pages. https://doi.org/10.1145/3173574.3173607

[26] Masa Ogata, Yuta Sugiura, Yasutoshi Makino, Masahiko Inami, and Michita Imai. 2013. SenSkin: Adapting Skin as a Soft Interface. In *Proceedings of the 26th Annual ACM Symposium on User Interface Software and Technology (UIST '13)*. Association for Computing Machinery, New York, NY, USA, 539–544. https://doi.org/10.1145/2501988.2502039

[27] Simon Olberding, Nan-Wei Gong, John Tiab, Joseph A. Paradiso, and Jürgen Steimle. 2013. A Cuttable Multi-Touch Sensor. In *Proceedings of the 26th Annual ACM Symposium on User Interface Software and Technology (UIST '13)*. Association for Computing Machinery, New York, NY, USA, 245–254. https://doi.org/10.1145/2501988.2502048

[28] Patrick Parzer, Adwait Sharma, Anita Vogl, Jürgen Steimle, Alex Olwal, and Michael Haller. 2017. SmartSleeve: Real-time Sensing of Surface and Deformation Gestures on Flexible, Interactive Textiles, using a Hybrid Gesture Detection Pipeline Patrick. In *Proceedings of the 30th Annual ACM Symposium on User Interface Software and Technology - UIST '17*. 565–577. https://doi.org/10.1145/3126594.3126652

[29] Stefan Schneegass and Alexandra Voit. 2016. GestureSleeve: using touch sensitive fabrics for gestural input on the forearm for controlling smartwatches. *Proceedings of the 2016 ACM International Symposium on Wearable Computers - ISWC '16* (2016), 108–115. https://doi.org/10.1145/2971763.2971797

[30] NXP Semiconductors. 2008. Application Note: Interfacing 4-wire and 5-wire resistive touchscreens.

[31] Jürgen Steimle. 2016. Skin–The Next User Interface. *Computer* 49, 4 (Apr 2016), 83–87. https://doi.org/10.1109/MC.2016.93

[32] Jürgen Steimle, Joanna Bergstrom-Lehtovirta, M. Weigel, Aditya S. Nittala, Sebastian Boring, Alex Olwal, and Kasper Hornbæk. 2017. On-Skin Interaction Using Body Landmarks. *Computer* 50, 10 (2017), 19–27. https://doi.org/10.1109/MC.2017.3641636

[33] Paul Strohmeier, Jarrod Knibbe, Sebastian Boring, and Kasper Hornbæk. 2018. ZPatch: Hybrid Resistive/Capacitive ETextile Input. In *Proceedings of the Twelfth International Conference on Tangible, Embedded, and Embodied Interaction (TEI '18)*. Association for Computing Machinery, New York, NY, USA, 188–198. https://doi.org/10.1145/3173225.3173242

[34] Martijn ten Bhömer, Ruggero Canova, and Eva de Laat. 2018. Body Inspired Design for Knitted Body-Protection Wearables. In *Proceedings of the 2018 ACM Conference Companion Publication on Designing Interactive Systems (DIS '18 Companion)*. Association for Computing Machinery, New York, NY, USA, 135–139. https://doi.org/10.1145/3197391.3205425

[35] Karen Vanderloock, Vero Vanden Abeele, Johan A.K. Suykens, and Luc Geurts. 2013. The Skweezee System: Enabling the Design and the Programming of Squeeze Interactions. In *Proceedings of the 26th Annual ACM Symposium on User Interface Software and Technology (UIST '13)*. Association for Computing Machinery, New York, NY, USA, 521–530. https://doi.org/10.1145/2501988.2502033

[36] Natalie Walsh. [n. d.]. How to use a dress form. https://www.instructables.com/id/How-to-Use-a-Dress-Form/

[37] Shutang Wang, Minghui He, Bingjuan Weng, Lihui Gan, Yingru Zhao, Ning Li, and Yannan Xie. 2018. Stretchable and Wearable Triboelectric Nanogenerator Based on Kinesio Tape for Self-Powered Human Motion Sensing. *Nanomaterials* 8, 9 (Aug 2018), 657. https://doi.org/10.3390/nano8090657

[38] Martin Weigel, Tong Lu, Gilles Bailly, Antti Oulasvirta, Carmel Majidi, and Jürgen Steimle. 2015. iSkin: Flexible, Stretchable and Visually Customizable On-Body Touch Sensors for Mobile Computing. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems (CHI '15)*. ACM, New York, NY, USA, 2991–3000. https://doi.org/10.1145/2702123.2702391

[39] Martin Weigel, Vikram Mehta, and Jürgen Steimle. 2014. More than Touch: Understanding How People Use Skin as an Input Surface for Mobile Computing. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '14)*. Association for Computing Machinery, New York, NY, USA, 179–188. https://doi.org/10.1145/2556288.2557239

[40] Martin Weigel, Aditya Shekhar Nittala, Alex Olwal, and Jürgen Steimle. 2017. SkinMarks: Enabling Interactions on Body Landmarks Using Conformal Skin Electronics. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems (CHI '17)*. Association for Computing Machinery, New York, NY, USA, 3095–3105. https://doi.org/10.1145/3025453.3025704

[41] Jacob O. Wobbrock, Andrew D. Wilson, and Yang Li. 2007. Gestures without Libraries, Toolkits or Training: A $1 Recognizer for User Interface Prototypes. In *Proceedings of the 20th Annual ACM Symposium on User Interface Software and Technology (UIST '07)*. Association for Computing Machinery, New York, NY, USA, 159–168. https://doi.org/10.1145/1294211.1294238

[42] Robert Xiao, Teng Cao, Ning Guo, Jun Zhuo, Yang Zhang, and Chris Harrison. 2018. LumiWatch: On-Arm Projected Graphics and Touch Input. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (CHI '18)*. Association for Computing Machinery, New York, NY, USA, Article Paper 95, 11 pages. https://doi.org/10.1145/3173574.3173669

[43] Juan Xie, Wei Pan, Zheng Guo, Shan Shan Jiao, and Ling Ping Yang. 2019. In situ polymerization of polypyrrole on cotton fabrics as flexible electrothermal materials. *Journal of Engineered Fibers and Fabrics* 14 (jan 2019), 155892501982744. https://doi.org/10.1177/1558925019827447

[44] Yang Zhang, Wolf Kienzle, Yanjun Ma, Shiu S. Ng, Hrvoje Benko, and Chris Harrison. 2019. ActiTouch: Robust Touch Detection for On-Skin AR/VR Interfaces. In *Proceedings of the 32nd Annual ACM Symposium on User Interface Software and Technology (UIST '19)*. Association for Computing Machinery, New York, NY, USA, 1151–1159. https://doi.org/10.1145/3332165.3347869

[45] Bo Zhou, Jingyuan Cheng, Mathias Sundholm, and Paul Lukowicz. 2014. From smart clothing to smart table cloth: Design and implementation of a large scale, textile pressure matrix sensor. In *Lecture Notes in Computer Science*, Vol. 8350 LNCS. Springer, Cham, 159–170. https://doi.org/10.1007/978-3-319-04891-8_14