

Knitted Force Sensors

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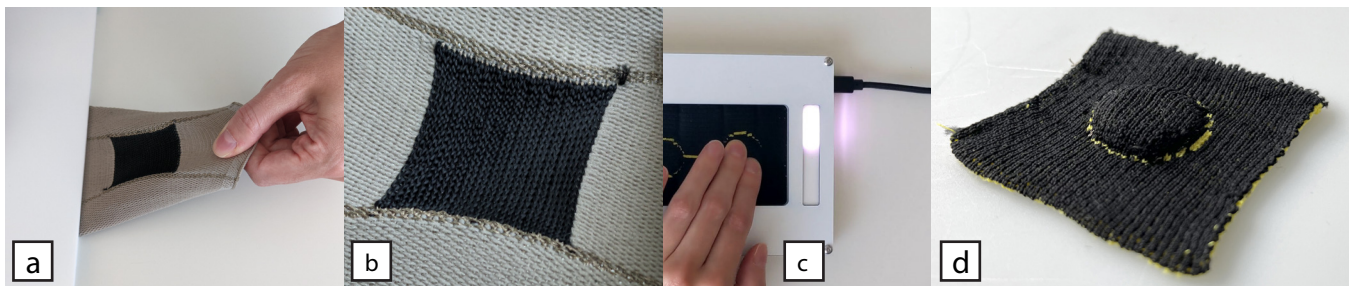


Figure 1: We implemented different knit-based sensors including a tubular knit stretch sensor (a, b) and a spacer knit pressure sensor (c, d).

ABSTRACT

In this demo, we present two types of knitted resistive force sensors for both pressure and strain sensing. They can be manufactured ready-made on a two-bed weft knitting machine, without requiring further post-processing steps. Due to their softness, elasticity, and breathability our sensors provide an appealing haptic experience. We show their working principle, discuss their advantages and limitations, and elaborate on different areas of application. They are presented as standalone demonstrators, accompanied by exemplary applications to provide insights into their haptic qualities and sensing capabilities.

CCS CONCEPTS

• Human-centered computing → Haptic devices.

KEYWORDS

knitting, spacer fabric, pressure sensor, tubular knit, strain sensor, resistive sensor, textile interface, e-textiles

ACM Reference Format:

Andreas Pointner, Thomas Preindl, Sara Mlakar, Roland Aigner, Mira Alida Haberfellner, and Michael Haller. 2022. Knitted Force Sensors. In *The Adjunct Publication of the 35th Annual ACM Symposium on User Interface Software and Technology (UIST '22 Adjunct)*, October 29–November 2, 2022, Bend, OR, USA. ACM, New York, NY, USA, 3 pages. <https://doi.org/10.1145/3526114.3558656>

1 INTRODUCTION

Throughout our lives, we are surrounded with textiles. They are ubiquitous and can be found in clothing, furniture, on floors and walls, etc. From this viewpoint, textiles afford interaction with other omnipresent technologies, such as electronic devices. Their favourable properties like flexibility, breathability, and softness can provide a more pleasant experience for the user. In this demo submission, we primarily focus on knitted resistive sensors that provide a real-time interaction sensation. We show textile pressure sensors based on spacer knits [1] and textile strain sensors based on tubular knits. Furthermore, we show how these sensors can be manufactured and how they can be applied to different applications.

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UIST '22 Adjunct, October 29–November 2, 2022, Bend, OR, USA

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ACM ISBN 978-1-4503-9321-8/22/10.

<https://doi.org/10.1145/3526114.3558656>

2 RELATED WORK

As research on electronic textile interfaces is gaining momentum, we see a large variety of applications [5, 11, 13, 14], with sensing technologies, including capacitive [7, 12, 14], resistive [3, 8], and inductive [6] methods. Those sensing methods rely on textile manufacturing processes which include weaving [13], knitting [9], as well as sewing [15] and embroidery [2] onto existing fabric. The groundwork for fabricating functional spacer knits was developed by Albaugh et. al, who investigated how to fabricate spacer fabrics with embedded functionality, using conductive yarn to enable capacitive sensing of touch and proximity [4].

3 KNITTED FORCE SENSORS

Common FSRs are multi-material elements, usually printed on plastic substrates. The piezo-resistive material is sandwiched between two conductive traces, that are in loose contact at rest. When under stress, the materials' surfaces are tightly compressed, which increases the contact area and consequently reduces the electrical resistance. We translated this concept to a single knit fabric. We used common polyamide (PA) yarn to provide the surrounding knit structure for embedding the sensor which also acts as insulator between the traces.

For knitting the traces, we used a silver plated PA conductive yarn HC40¹ from Madeira with a linear resistance of $<300 \Omega/\text{m}$. For the resistive part of the sensor, we used a Resistat P6204 H100i² from Shakespeare Conductive Fibers LLC, a polyester yarn with conductive sheathing and an average linear resistance of $1.5 \text{ M}\Omega/\text{cm}$. We manufactured our knitted sensors on a SWG061N2³ 15 gauge flat-bed knitting machine from Shima Seiki.

To generate the knit patterns, we used the Knitout high-level knit description language [10] as an intermediate format. Knitout is a human-readable knit program description that greatly simplifies manual edits and quick visual verification using the associated tools [16]. We then converted the Knitout files to target DAT format that was further used in Shima Seiki KnitPaint for the generation of the binary machine-program files.

3.1 Strain Sensors

Tubular knitted strain sensors consist of conductive thread traces connecting both ends of a tubular field that is knitted on one side with resistive material and on the other with insulating polyamid yarn (cf. Figure 2a). At rest, the individual loops of the resistive area are in loose contact, which translates to high electrical resistance between the two conductive traces. Applying a strain force leads to tighter contact of interlocked loops and a drop in resistance. As the sensor's resistance correlates to the ratio of the resistive field height and width, the sensor area can easily be re-shaped according to the desired resistance ranges.

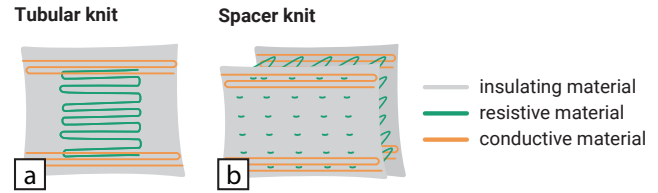


Figure 2: In a) the resistive tubular knit sensor layout is shown, while b) depicts the spacer structure with resistive yarns inlaid as filler material.

3.2 Pressure Sensors

Spacer fabrics are volumetric knits, created with nylon monofilaments acting as filler material being inlaid between two opposing knit faces in order to fill up volume and provide elasticity. To enhance this knit with sensing capabilities, we added a resistive material, inlaid alongside the nylon (cf. Figure 2 b). At rest, the filler structure exhibits high resistance. When compressed, the number of contacts increases, resulting in a drop of the overall resistance. This "3D" structure provides pleasant haptic feedback upon actuation.

4 APPLICATION DEMONSTRATORS

At UIST 2022, we will exhibit a set of different functional prototypes showing many variations of knitted sensors. We will show stretch sensing capabilities of resistive tubular fields, as well as the pressure sensing performance of our spacer knits. We will demonstrate an application of the stretch sensor, in which the user can close blinds by pulling on the fabric, emulating the movement of closing curtains. We will also show a use-case of a textile pressure sensor being used as a button to control functions of a digital UI, like scrolling. This application shows how knitted sensors can be used to embed digital functions into furniture. Attendees will be encouraged to experience the demonstrators firsthand and get a sense of both the haptic qualities and sensing performance. Additionally, we will exhibit non-functional samples showing additional sensor variations and providing more insights into possible sensor layouts.

5 FUTURE APPLICATIONS

Our knitted force resistive sensors offer several potential application possibilities. The tubular sensors could be used for detecting textile deformation or weight distribution of a human body in a free-hanging textile, for example in a baby stroller. Soft-spacer pressure sensors could provide a potential replacement for foam-based upholstery, while providing additional sensing capabilities. Their convex surface structure also affords easier discoverability in out-of-sight haptic user interfaces. The continuous input provides more precise user control resulting in a more reactive textile interface.

The knitting technique also offers a unique benefit of the one-layered interfaces being more sustainable, as each material can be separated and recycled through the process of unraveling.

Combining all their benefits, we believe knitted force sensors have the potential to significantly improve the performance and usability of future textile sensing as well as textile user interfaces.

¹[https://shop.madeira.co.uk/hc-40-2500m-cone-\(high-conductive\)_hc40-xxx.htm](https://shop.madeira.co.uk/hc-40-2500m-cone-(high-conductive)_hc40-xxx.htm)

²<https://shakespeare-pf.com/product/polyester/>

³https://www.shimaseiki.com/product/knit/swg_n2/

ACKNOWLEDGMENTS

Our thanks goes to Jim McCann and the CMU Textiles Lab for kindly providing their Knitout tools.

This research is part of the COMET project TextileUX (No. 865791, which is funded within the framework of COMET – Competence Centers for Excellent Technologies by BMVIT, BMDW, and the State of Upper Austria. The COMET program is handled by the FFG.

REFERENCES

- [1] Roland Aigner, Mira Alida Haberfellner, and Michael Haller. 2022. spaceR: Knitting Ready-Made, Tactile, and Highly Responsive Spacer-Fabric Force Sensors for Continuous Input. In *Proceedings of the 35th Annual ACM Symposium on User Interface Software and Technology (UIST '22)*. Association for Computing Machinery, New York, NY, USA. DOI: <http://dx.doi.org/10.1145/3526113.3545694>
- [2] Roland Aigner, Andreas Pointner, Thomas Preindl, Rainer Danner, and Michael Haller. 2021. TextYZ: Embroidering Enameled Wires for Three Degree-of-Freedom Mutual Capacitive Sensing. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems (CHI '21)*. Association for Computing Machinery, New York, NY, USA, Article 499, 12 pages. DOI: <http://dx.doi.org/10.1145/3411764.3445479>
- [3] Roland Aigner, Andreas Pointner, Thomas Preindl, Patrick Parzer, and Michael Haller. 2020. Embroidered Resistive Pressure Sensors: A Novel Approach for Textile Interfaces. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems (CHI '20)*. Association for Computing Machinery, New York, NY, USA, 1–13. <https://doi.org/10.1145/3313831.3376305>
- [4] Lea Albaugh, James McCann, Scott E. Hudson, and Lining Yao. 2021. Engineering Multifunctional Spacer Fabrics Through Machine Knitting. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems (CHI '21)*. Association for Computing Machinery, New York, NY, USA, Article 498, 12 pages. DOI: <http://dx.doi.org/10.1145/3411764.3445564>
- [5] Leah Buechley, Mike Eisenberg, Jaime Catchen, and Ali Crockett. 2008. The LilyPad Arduino: Using Computational Textiles to Investigate Engagement, Aesthetics, and Diversity in Computer Science Education. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '08)*. Association for Computing Machinery, New York, NY, USA, 423–432. DOI: <http://dx.doi.org/10.1145/1357054.1357123>
- [6] Jun Gong, Yu Wu, Lei Yan, Teddy Seyed, and Xing-Dong Yang. 2019. Tessuto: Contextual Interactions on Interactive Fabrics with Inductive Sensing. In *Proceedings of the 32nd Annual ACM Symposium on User Interface Software and Technology (UIST '19)*. Association for Computing Machinery, New York, NY, USA, 29–41. DOI: <http://dx.doi.org/10.1145/3332165.3347897>
- [7] Paul Holleis, Albrecht Schmidt, Susanna Paasovaara, Arto Puikkonen, and Jonna Häkkinen. 2008. Evaluating Capacitive Touch Input on Clothes. In *Proceedings of the 10th International Conference on Human Computer Interaction with Mobile Devices and Services*. Association for Computing Machinery, New York, NY, USA, 81–90. DOI: <http://dx.doi.org/10.1145/1409240.1409250>
- [8] Hughes-Riley, Oliveira, and Dias. 2019. A Knitted Multi-Junction Pressure Sensor That Uses Electrical Resistance to Determine the Applied Pressure: Development and Characterization. *Proceedings* 32, 1 (2019), 3. DOI: <http://dx.doi.org/10.3390/proceedings2019032003>
- [9] Yiyue Luo, Yunzhu Li, Pratyusha Sharma, Wan Shou, Kui Wu, Michael Foshey, Beichen Li, Tomás Palacios, Antonio Torralba, and Wojciech Matusik. 2021. Learning human–environment interactions using conformal tactile textiles. *Nature Electronics* 4 (3 2021), 193–201.
- [10] James McCann. 2017. The Knitout (.k) File Format. (2017). <https://textiles-lab.github.io/knitout/knitout.html>
- [11] Alex Olwal, Jon Moeller, Greg Priest-Dorman, Thad Starnier, and Ben Carroll. 2018. I/O Braid: Scalable Touch-Sensitive Lighted Cords Using Spiraling, Repeating Sensing Textiles and Fiber Optics. In *Proceedings of the 31st Annual ACM Symposium on User Interface Software and Technology (UIST '18)*. Association for Computing Machinery, New York, NY, USA, 485–497. DOI: <http://dx.doi.org/10.1145/3242587.3242638>
- [12] E. R. Post, M. Orth, P. R. Russo, and N. Gershensfeld. 2000. E-broidery: Design and Fabrication of Textile-based Computing. *IBM Syst. J.* 39, 3-4 (July 2000), 840–860. DOI: <http://dx.doi.org/10.1147/sj.393.0840>
- [13] Ivan Poupyrev, Nan-Wei Gong, Shiho Fukuhara, Mustafa Emre Karagozler, Carsten Schwesig, and Karen E. Robinson. 2016. *Project Jacquard: Interactive Digital Textiles at Scale*. Association for Computing Machinery, New York, NY, USA, 4216–4227. <https://doi.org/10.1145/2858036.2858176>
- [14] Richard Vallett, Ryan Young, Chelsea Knittel, Youngmoo Kim, and Genevieve Dion. 2016. Development of a Carbon Fiber Knitted Capacitive Touch Sensor. *MRS Advances* 1, 38 (2016), 2641–2651. DOI: <http://dx.doi.org/10.1557/adv.2016.498>
- [15] Anita Vogl, Patrick Parzer, Teo Babic, Joanne Leong, Alex Olwal, and Michael Haller. 2017. StretchEBand: Enabling Fabric-Based Interactions through Rapid Fabrication of Textile Stretch Sensors. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems (CHI '17)*. Association for Computing Machinery, New York, NY, USA, 2617–2627. DOI: <http://dx.doi.org/10.1145/3025453.3025938>
- [16] Tianhong Catherine Yu and James McCann. 2020. Coupling Programs and Visualization for Machine Knitting. In *Symposium on Computational Fabrication (SCF '20)*. Association for Computing Machinery, New York, NY, USA, Article 7, 10 pages. DOI: <http://dx.doi.org/10.1145/3424630.3425410>