Plug-n-play e-knit: prototyping large-area e-textiles using machine-knitted magnetically-repositionable sensor networks

Yifan Li
The University of Tokyo
Japan
yifan217@akg.t.u-tokyo.ac.jp

Ryo Takahashi
The University of Tokyo
Japan
takahashi@akg.t.u-tokyo.ac.jp

Wakako Yukita
The University of Tokyo
Japan
yukita@bhe.t.u-tokyo.ac.jp

Kanata Matsutani
Nagoya Institute of Technology
Japan
k.matsutani.640@stn.nitech.ac.jp

Cedric Caremel
The University of Tokyo
Japan
cedric@akg.t.u-tokyo.ac.jp

Yuhiro Iwamoto
Nagoya Institute of Technology
Japan
iwamoto.yuhiro@nitech.ac.jp

Sunghoon Lee
The University of Tokyo
Japan
sunghoon@ntech.t.u-tokyo.ac.jp

Tomoyuki Yokota
The University of Tokyo
Japan
yokota@ntech.t.u-tokyo.ac.jp

Takao Someya
The University of Tokyo
Japan
someya@ee.t.u-tokyo.ac.jp

Yoshihiro Kawahara
The University of Tokyo
Japan
kawahara@akg.t.u-tokyo.ac.jp

Figure 1: Overview of plug-n-play e-knit. Plug-n-play e-knit is a (a) machine-knitted e-textile prototyping tool, which enables (b) large-area, reconfigurable and on-textile sensing. (c) It also provides a non-invasive sensor connection method by using soft magnet.

Abstract

Prototyping electronic textile involves embedding electronic components into fabrics to develop smart clothing with specific functionalities. However, this process is still challenging since the complicated wiring setup is required during experimental phases. This paper presents plug-n-play e-knit, a large-scale, repositionable e-textile for providing trial-and-error prototyping platforms across the textile. Plug-n-play e-knit leverages industrial digital knitting machines loaded with conductive thread to automatically embed a

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communication and power supply network into garments, in addition to using soft magnet connectors to rearrange electronic components while preserving the stretchability of the garment. These combinations enable users to quickly establish e-textile sensor networks, and moreover test the performance and optimal placement of the electric devices on the textile. We demonstrated that our textiles leveraging custom I^2C protocols could achieve the motion-resilient motion-tracking sensor network over a 2700 cm^2 garment area.

CCS Concepts

• **Human-centered computing → Interaction devices**.

Keywords

E-textiles, e-knit, PME, wearable, prototyping tool, smart clothing

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1 INTRODUCTION

Developing electronic textile (E-textile) involves repeated disassembly of integrated electronic devices to find the optimal device position in the field of activity recognition and healthcare [6, 9, 19]. For example, monitoring lower-limb rehabilitation requires the precise placement of sensors at different patients' injured joints and muscles [33]. E-textile prototyping tools provide means to quickly test and evaluate the proof-of-concept e-textiles [8, 24, 29]. However, current e-textile prototyping tools use invasive connection methods such as stitching [1], welding [4], adhesives [19], causing the textile damage when connecting the sensing module with the e-textiles. The lack of a method for integrating large-area conductive threads restricts the possible installation positions of the sensing module, preventing it from covering a large portion of the body [11, 33].

To address the issues, we propose plug-n-play e-knit, a large-scale, reconfigurable, scalable e-textile prototyping tool. The plug-n-play e-knit design includes 1) the machine-knitted textile-based communication and power supply network for sensing modules on the textiles and 2) the soft magnet connector to rearrange these modules to the textile. First, the knitting machine directly integrates stretchable communication and power supply network into the garment at scale, enabling to freely place the modules across the textile. Then, the soft magnet connector compromised of Permanent Magnet Elastomer (PME) [22] offers repeated replacement of the sensing modules without damaging the textile and hindering the user motions. Sensing modules based on customized I^2C protocols can function by simply touching the corresponding position of the conductive threads. With these configurations, plug-n-play e-knit provides an e-textile platform that allows repeatable on-textile sensor performance tests and e-textile application development such as body motion tracking.

2 RELATED WORK

2.1 E-textiles

Since daily clothing covers a large area of the human body, the integration of electric functionality into the clothing enables the monitoring of comprehensive physiological and environmental signals across the body. Prior research has proposed large-scale, highly integrated e-textiles using two types of connectivity: wired approach and wireless approach. As for the wired approach, researchers typically incorporate conductive threads into textiles via weaving [32], knitting [23], and embroidery [7, 31], subsequently connecting them to sensor boards through welding or stitching [16]. Wired e-textiles typically exhibit higher energy efficiency [25]. By contrast, the wireless approach does not necessitate the direct integration of electronic components into textiles. To achieve non-contact communication and power transfer, researchers incorporate conductive coils into textiles by sewing [3] or printing [14]. These coils act as inductors and form an inductive coupling or Near Field Communication (NFC) terminal [15, 26–28], enabling electronic devices placed near them to receive power and exchange data. However, achieving large-scale, repositionable, and customizable e-textiles remains highly challenging because of transmission noise [18], the lack of lightweight, and non-invasive connectors [25].

2.2 Plug-n-Play Wearables

In prototyping e-textiles, the plug-and-play feature facilitates the easy attachment and removal of electronic components, which not only reduces the debugging time for developers but also minimizes the damage to the textiles caused by component disassembly. There are various types of the plug-n-play connections including primarily employs snap fasteners [10, 13], pogo pins and magnets [21], pin headers [17], conductive hooks [33], and adhesives [24]. However, these methods have issues such as poor stretchability, causing damage to textiles, and inconveniences in changing the positions of sensing modules [25].

3 PLUG-N-PLAY E-KNIT DESIGN

Figure 3a shows the system overview of plug-n-play e-knit. Our system consists of three parts: 1) an e-knit with several groups of exposed conductive lines, 2) soft magnet connector which is compatible with a stretchable e-knit, and 3) sensing modules connected with the e-knit via the magnet connectors.

3.1 Machine-knitted E-textiles

In Figure 2, we divide the conductive threads (AGposs, Mitsufuji Corporation) into several groups, arranged horizontally on the garment and they maintain a certain distance to allow for PME installation and sensing module placement. Each group contains six equidistant horizontal conductive threads to form different channels, independent and assigned to transmit different signals. The top and bottom channels power the modules, providing a 5V power supply line (i.e., VCC) and a ground line (i.e., GND) signal. While The I^2C protocol is promising for plug-n-play e-knit due to its minimal interfaces, fewer pinouts and multiple slave sensors communication, I^2C suffers from noise interference and limited communication

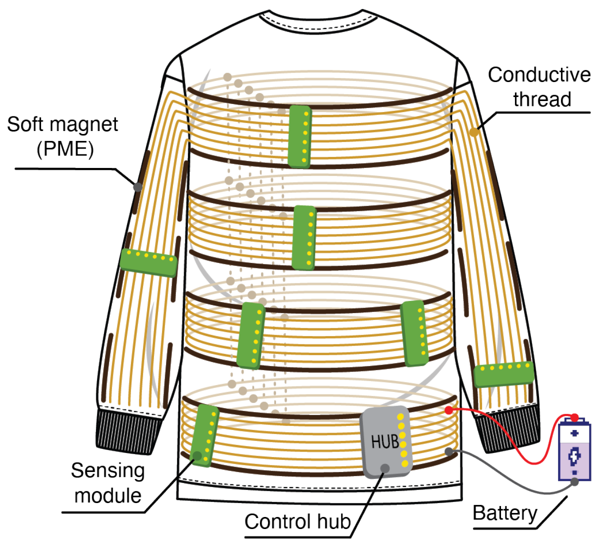

Figure 2: Design overview of plug-n-play e-knit comprising the textile garment, sensing module, soft magnet and control hub.

distance. Consequently, we utilized Differential I^2C to diminish signal interference on textiles and increase the communication range. Differential I^2C divides the two traditional I^2C signals (SDA, SCL) into four differential signals with the same magnitude and opposite polarity (SDA+, SDA-, SCL+, SCL-) for transmission, and integrates them into signals with double amplitude at the receiver end to enhance noise immunity. These signals are transmitted through 2nd to 5th channels. Then, we can fabricate the e-textile, as Figure 3 shows.

3.2 Soft Magnet Connector

The plug-and-play e-textile prototyping connector should be lightweight and stretchable, in addition to having a strong connection force. Prior work has proposed conductive hook-and-loop [20], conductive barb [33], and soft magnets as plug-and-play connectors. Among them, PME [22], one of the soft magnets, is a stretchable neodymium magnet (see Figure 4a), fabricated by mixing a polyurethane resin with a neodymium powder. The mixed polyurethane resin is molded into long strips and magnetized. We use adhesive to attach the PME shaped into long strips at the edge of each wiring group, so that the flexible PCBs equipped with four neodymium magnets can be strongly connected with the wiring. We test the stretchability of PME in the Tensile and Compression Testing Machine (MCT-2150W, A&D Company Ltd.) with three 40 mm $*$ 5 mm sized PME samples. The result is shown in Figure 4b. The 5 mm PME provides enough stretchability for daily wear.

3.3 Sensing Module

To implement various functions on e-textiles while maintaining wear comfort, we need lightweight and customizable sensing modules. The energy and signal of the plug-n-play e-knit can be transmitted throughout the entire garment, providing the conditions for this. Here, we introduce the IMU sensing module as an example. As shown in Figure 5, the sensing module consists of flexible PCBs with low-power MCU (STM32L432KC, STMicroelectronics), Low Dropout(LDO) (TLV76733, Texas Instruments), IMU sensor (ICM20948, TDK InvenSense), Differential I^2C buffer chip (PCA9615, NXP Semiconductors) and spring connector which align the position of conductive threads. We employ adhesive to attach magnets at the edge of sensing modules for the magnet connection with the PME. When they are connected, the electric connectors are also in contact with the conductive threads on the textile (Figure 1c), initiating their operation. Each module receives power from a central hub and communicates with the hub via the differential I^2C protocol. The use of lightweight flexible PCB stably records the 9-axis IMU motion data against user motions. The module is 40 mm*15 mm size and 1 g weight.

4 EVALUATION

This section evaluates the communication and connection stability of the plug-n-play e-knit.

4.1 Signal Attenuation for Different Body Placement

To construct large-scale e-textile prototyping, the maximum communication range between the sensing modules and hubs must be over 1.5 m (i.e., the distance between the left wrist and hem of the garment). However, the signal attenuation in the long conductive wire causes communication failure. Therefore, we tested the performance of the two longest channels in the plug-n-play e-knit. We chose conductive paths between the ends of the two sleeves and one sleeve to the corner of the garment. We placed one sensing module, which serves as the data transmitter, on the right wrist (Position 1). Then, we tested the signal attenuation at the eight positions (Position 2-9), as shown in Figure 6a. The voltage of the differential I^2C signal (i.e., SCL signal) at the 8 positions and the transmitting signal from the data transmitter are shown in Figure 6b. Although there is a reduction in the signal at the edge (Position 9), the waveform of the signal does not distort, and the difference between the high and low levels remains clear. As a result, the plug-n-play e-knit enables the differential I^2C communication without the signal loss.

4.2 Connection Stability of Soft Magnet Connector

Since the e-textile typically functions during the user's movement, the soft magnet connection in the plug-n-play e-knit needs to be robust against user motions. We evaluated the robustness by monitoring the communication status of the five sensing modules during four types of user motions including walking, running, jumping and upper body rotating. Note that the sensing modules were placed at the left wrist, right wrist, back, chest, and waist and the motion period was 5 seconds. Figure 6c shows the remaining number of the sensing modules for each motion test 50 times. The result shows that plug-n-play e-knit shows sufficient connection stability except for jumping. Since the jumping causes the force of 0.03 N to the sensing module, we need to increase the surface magnetic force of the PME by at least 3 times.

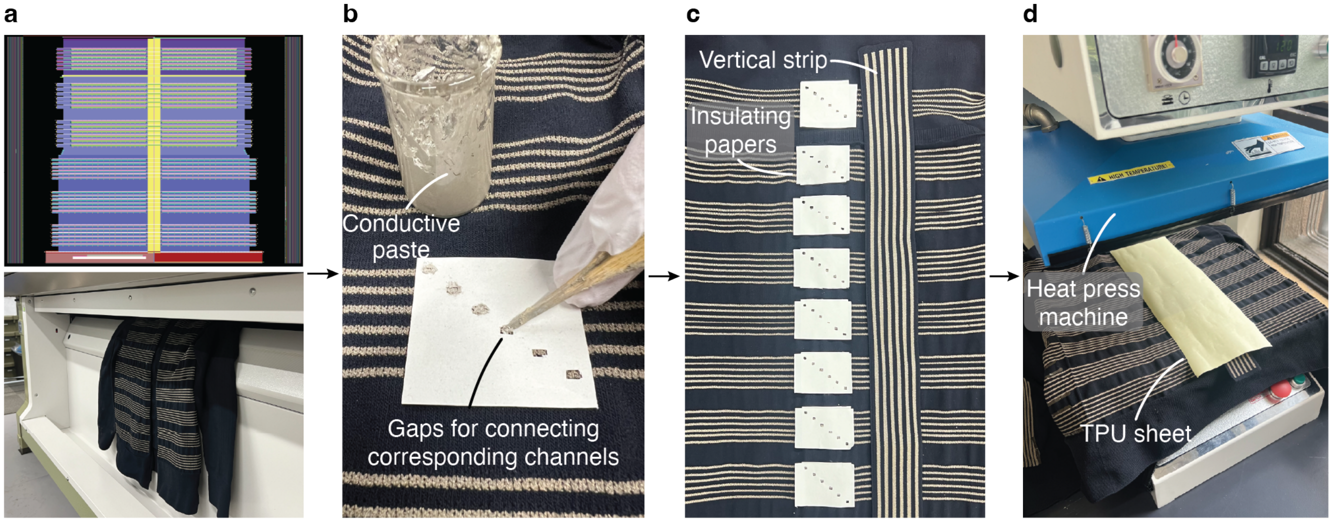

Figure 3: Fabrication process of the textile including (a) designing the thread pattern and producing with industrial knitting machine (MACH2XS, SHIMA SEIKI MFG., LTD.), (b) covering irrelevant channels' conductive threads with square pieces of paper to ensure insulation and coat corresponding channels with conductive paste to enhance conductivity, (c) aligning the gaps in each channel with the corresponding channels of a vertical conductive strip, (d) affixing the strip using Thermoplastic Polyurethanes (TPU) under a heat press machine at 0.7 MPa **and** 120 °C**.**

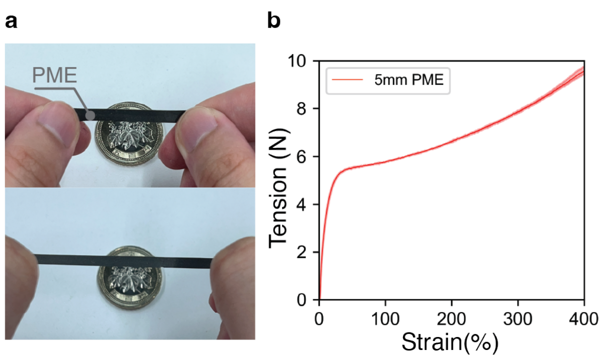

Figure 4: (a) A close-up of 5 mm **wide PME's stretchability. (b) Relationship between the tension and the strain of the** 5 mm **wide PME. The solid line denotes the mean and the shaded areas depict the maximum deviation of the three PME testing samples.**

5 APPLICATION EXAMPLES

5.1 The Optimal Sensor Placement for Motion Capturing

Previous e-textile prototype tools might necessitate complex circuit connections [9] or invasive sensor installation methods [5], whereas our plug-n-play e-knit offers a large-scale, high-resolution experiment approach. For example, the user can keep the upper arm stationary while making a forward flexing movement with the forearm. Meanwhile, two OptiTrack markers were placed on the wrist and elbow to obtain ground-truth data on forearm movement. Then, select eight equidistant positions from the wrist to the shoulder to place the IMU functional module and perform a forearm flexion experiment for each position, as shown in Figure 7a, to test which position can get the most accurate forearm movement data. Since the upper arm remains stationary, we can use the ground truth data as a reference for the angle of forearm flexion and compare the Mean Per Joint Rotation Error (MPJRE) of the IMU at the eight positions.

As shown in Figure 7c, we can obtain the most accurate data below the wrist (8.24°), rather than at the wrist itself (10.63°). This is due to unconscious wrist twisting during forearm movement. The accuracy of the data diminishes greatly behind the elbow joint. During the experiment, the user just needs to plug and unplug the FPCB board to test its performance at different positions on the e-textile. This not only improves the efficiency of prototype design but also reduces the damage to the textile caused by repeated invasive testing. Note that the data from above and below the elbow was obtained simultaneously with two IMU modules, indicating that our system supports simultaneous testing with multiple sensing modules. Given sufficient modules, we can simultaneously measure the movement at eight positions.

5.2 Skin Temperature Measurement

Human skin temperature varies across different body parts [12]. These data can be used to estimate stress levels [30], and understand exercise efficiency [2]. In previous studies, skin temperature was obtained through thermal imaging [2], electronic skin [34], and e-textiles [32]. These methods are either unsuitable for daily monitoring or do not allow for adjusting the measurement position

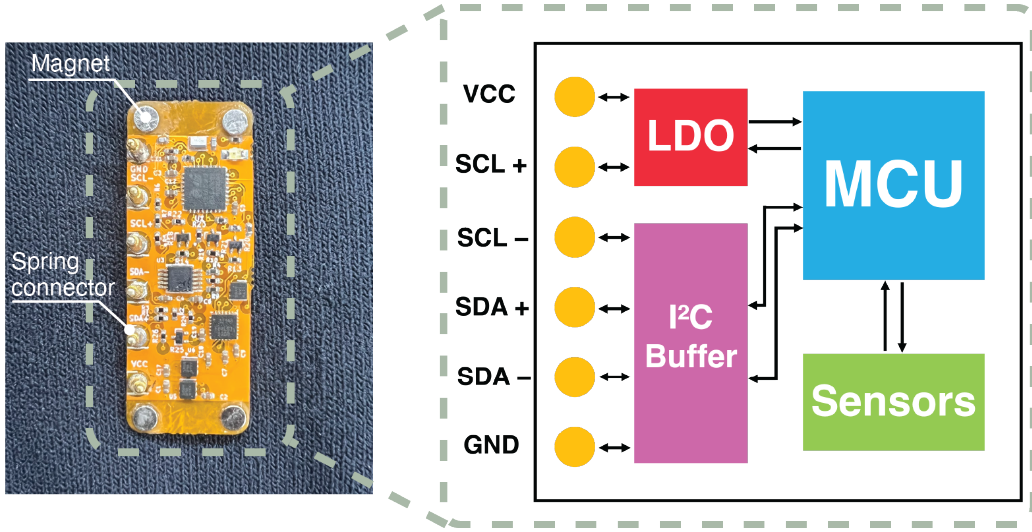

Figure 5: System overview of the sensing module.

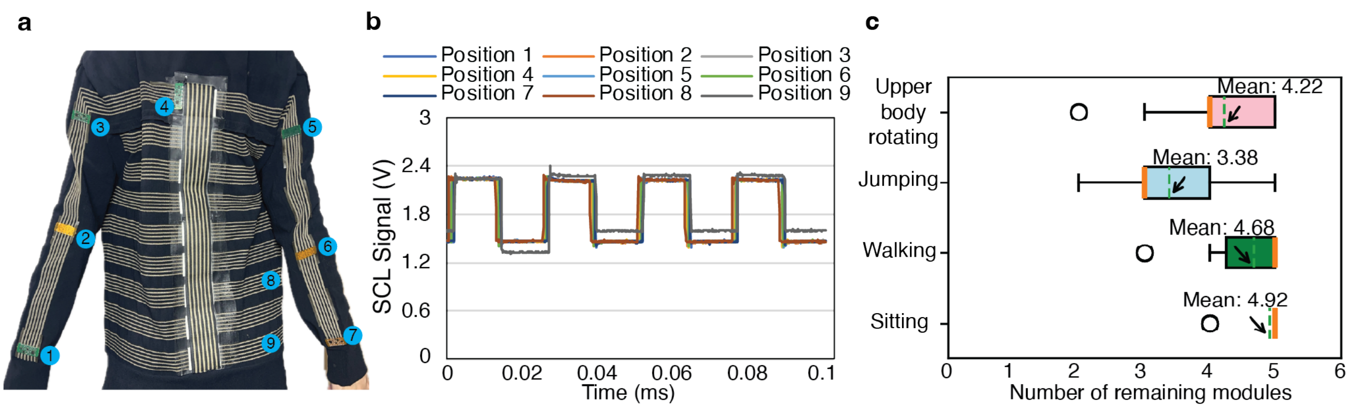

Figure 6: (a) The setup of evaluating 9 position's signal attenuation. (b) Comparison of SCL-signals acquired at 9 locations within 0.1 ms**. (c) Comparison of the number of 5 intact sensing modules left after different movements.**

according to the users' needs. The plug-n-play e-knit provides an integrated and reconfigurable on-textile skin temperature measurement method. For example, we place the data acquisition hub at the corner of the garment, and then place sensing modules equipped with temperature sensors at the wrist, upper arm, infra-clavicular, and stomach areas and attach them closely to the body for measurement. The calibrated results are shown in Figure 8c. During the experiment, users can rearrange the sensing modules in a large area of the garment and get real-time temperature data.

6 DISCUSSION

6.1 Signal Loss against User Movement

Current e-textiles need the uncovered differential I^2C signal lines for the direct connection of the sensing modules. Such the exposed signal lines cause the undesired contact of the adjacent signal lines, resulting in the communication error, specifically around the arm. Using the wireless e-textile only around the arm [27, 28] could mitigate this issue by providing the non-contact connection between the wiring-coated e-textiles and the sensing modules.

6.2 Disconnection of Differential I^2C Signal Lines

As described in Section 4.1, 7.4% area of the differential I^2C signal lines is disconnected with the central hub, owing to the misalignment of the vertical conductive strips with the horizontal Differential I^2C signal lines. Although we manually adjust the position of the vertical strips when using the heat press, we will explore the stable connection between the vertical and horizontal signal lines with the development of the alignment jig.

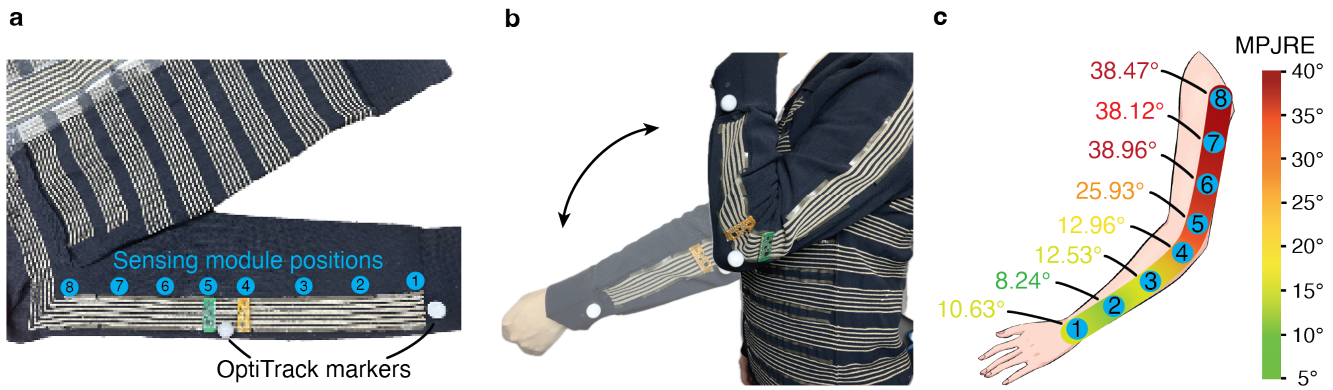

Figure 7: (a) The sensing module is positioned at eight points between the wrist and shoulder to actively test (b) the optimal placement for capturing forearm movement, and (c) get Mean Per Joint Rotation Error (MPJRE) data for each position.

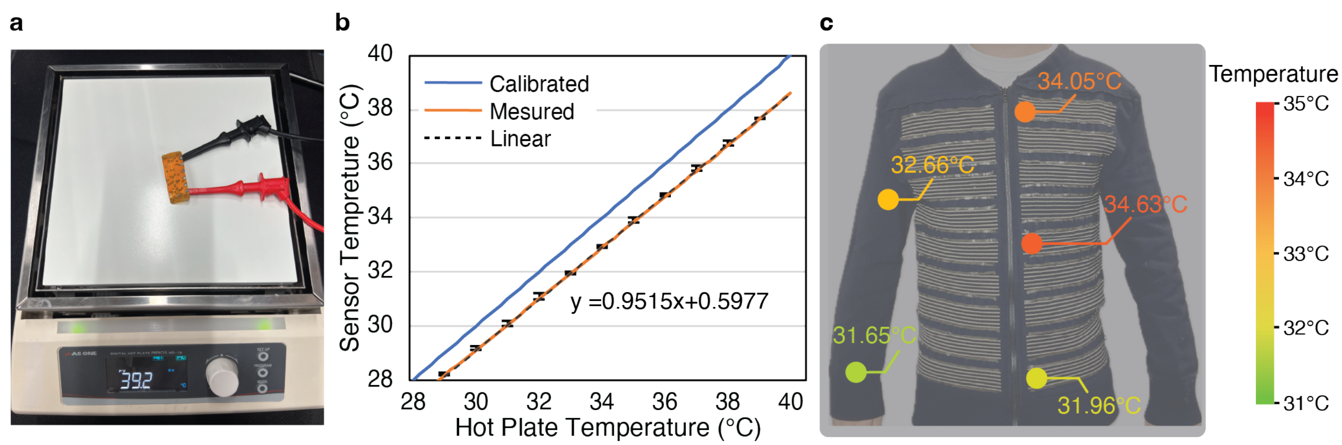

Figure 8: The temperature sensor is (a) placed on a hot plate (ND-1A, AS ONE) and (b) gets the linear fitting expression and graph of temperature characterization with the calibrated result. (c) Then we place the sensing board at 5 positions to get skin temperature data.

7 CONCLUSION

This paper introduces the plug-n-play e-knit toward enabling the prototyping tool of the large-area, non-invasive e-textile. Combining the machine-knitted e-textile with the soft magnet connector, the plug-n-play e-knit allows users to freely and repeatably rearrange the sensing modules across the e-textiles. The plug-n-play e-knit demonstrated its large-area on-textile prototyping ability such as capturing arm movements and measuring skin temperature at scale. The stable connectivity of the sensing modules against user's harsh movement could be one of our main future work. We strongly believe the large-scale, non-invasive design of the plug-n-play e-knit could promote the ubiquitous development of smart clothing with various functionalities.

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References

[1] Leah Buechley and Michael Eisenberg. 2008. The LilyPad Arduino: Toward Wearable Engineering for Everyone. *IEEE Pervasive Computing* 7, 2 (April 2008), 12–15. https://doi.org/10.1109/MPRV.2008.38

[2] Monika Chudecka and Anna Lubkowska. 2012. The use of thermal imaging to evaluate body temperature changes of athletes during training and a study on the impact of physiological and morphological factors on skin temperature. *Human movement* 13, 1 (2012), 33–39.

[3] Kristel Fobelets, Kris Thielemans, Abhinaya Mathivanan, and Christos Papavassiliou. 2019. Characterization of Knitted Coils for e-Textiles. *IEEE Sensors Journal* 19, 18 (2019), 7835–7840. https://doi.org/10.1109/JSEN.2019.2917542

[4] Nicolas P. Fromme, Yifan Li, Martin Camenzind, Claudio Toncelli, and René M. Rossi. 2021. Metal-Textile Laser Welding for Wearable Sensors Applications. *Advanced Electronic Materials* 7, 4 (2021), 2001238. https://doi.org/10.1002/aelm.

202001238

[5] Kamil Garbacz, Lars Stagun, Sigrid Rotzler, Markus Semenec, and Malte von Krshiwoblozki. 2021. Modular E-Textile Toolkit for Prototyping and Manufacturing. *Proceedings* 68, 1 (2021), 5. https://doi.org/10.3390/proceedings2021068005

[6] Linsey Griffin, Crystal Compton, and Lucy E. Dunne. 2016. An analysis of the variability of anatomical body references within ready-to-wear garment sizes. In *Proceedings of the 2016 ACM International Symposium on Wearable Computers (ISWC '16)*. Association for Computing Machinery, New York, NY, USA, 84–91. https://doi.org/10.1145/2971763.2971800

[7] Nur Al-huda Hamdan, Simon Voelker, and Jan Borchers. 2018. Sketch Stitch: Interactive Embroidery for E-textiles. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (Montreal QC, Canada) *(CHI '18)*. Association for Computing Machinery, New York, NY, USA, 1–13. https://doi.org/10.1145/3173574.3173656

[8] Ahyoung Han, Kwangyun Wohn, and Jaehong Ahn. 2021. Towards new fashion design education: learning virtual prototyping using E-textiles. *International Journal of Technology and Design Education* 31, 2 (April 2021), 379–400. https://doi.org/10.1007/s10798-019-09558-w

[9] Chris Hill, Michael Schneider, Ann Eisenberg, and Mark D. Gross. 2021. The ThreadBoard: Designing an E-Textile Rapid Prototyping Board. In *Proceedings of the Fifteenth International Conference on Tangible, Embedded, and Embodied Interaction (TEI '21)*. Association for Computing Machinery, New York, NY, USA, 1–7. https://doi.org/10.1145/3430524.3440642

[10] Lee Jones, Sara Nabil, and Audrey Girouard. 2020. Swatch-bits: Prototyping E-textiles with Modular Swatches. In *Proceedings of the Fourteenth International Conference on Tangible, Embedded, and Embodied Interaction (TEI '20)*. Association for Computing Machinery, New York, NY, USA, 893–897. https://doi.org/10.1145/3374920.3374971

[11] 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

[12] Chan Mi Lee, Seon-Pil Jin, Eun Jin Doh, Dong Hun Lee, and Jin Ho Chung. 2019. Regional variation of human skin surface temperature. *Annals of Dermatology* 31, 3 (2019), 349–352.

[13] Jacek Leśnikowski. 2016. Research on Poppers Used as Electrical Connectors in High Speed Textile Transmission Lines. *Autex Research Journal* 16, 4 (2016), 228–235. https://doi.org/doi:10.1515/aut-2016-0025

[14] Yi Li, Neil Grabham, Russel Torah, John Tudor, and Steve Beeby. 2018. Textile-based flexible coils for wireless inductive power transmission. *Applied Sciences* 8, 6 (2018), 912.

[15] Rongzhou Lin, Han-Joon Kim, Sippanat Achavananthadith, Ze Xiong, Jason K. W. Lee, Yong Lin Kong, and John S. Ho. 2022. Digitally-embroidered liquid metal electronic textiles for wearable wireless systems. *Nature Communications* 13, 1 (April 2022), 2190. https://doi.org/10.1038/s41467-022-29859-4

[16] Torsten Linz, Christine Kallmayer, Rolf Aschenbrenner, and Herbert Reichl. 2005. Embroidering electrical interconnects with conductive yarn for the integration of flexible electronic modules into fabric. In *Ninth IEEE International Symposium on Wearable Computers (ISWC'05)*. IEEE, 86–89.

[17] Eric Markvicka, Steven Rich, Jiahe Liao, Hesham Zaini, and Carmel Majidi. 2018. Low-cost wearable human-computer interface with conductive fabric for STEAM education. In *2018 IEEE Integrated STEM Education Conference (ISEC)*. 161–166. https://doi.org/10.1109/ISECon.2018.8340469

[18] Akihito Noda and Hiroyuki Shinoda. 2019. Inter-IC for Wearables (I2We): Power and Data Transfer Over Double-Sided Conductive Textile. *IEEE Transactions on Biomedical Circuits and Systems* 13, 1 (2019), 80–90. https://doi.org/10.1109/TBCAS.2018.2881219

[19] Korine A. Ohiri, Connor O. Pyles, Leslie H. Hamilton, Megan M. Baker, Matthew T. McGuire, Eric Q. Nguyen, Luke E. Osborn, Katelyn M. Rossick, Emil G. McDowell, Leah M. Strohsnitter, and Luke J. Currano. 2022. E-textile based modular sEMG suit for large area level of effort analysis. *Scientific Reports* 12, 1 (June 2022), 9650. https://doi.org/10.1038/s41598-022-13701-4

[20] RD Seager, Alford Chauraya, Shiyu Zhang, William Whittow, and Y Vardaxoglou. 2013. Flexible radio frequency connectors for textile electronics. *Electronics Letters* 49, 22 (2013), 1371–1373.

[21] Sensoria Fitness. n.d. [n. d.]. https://www.sensoriafitness.com/

[22] Sahil Shembekar, Mitsuhiro Kamezaki, Peizhi Zhang, He Zhuoyi, Yuhiro Iwamoto, Yasushi Ido, Hiroyuki Sakamoto, and Shigeki Sugano. 2021. Development of a Permanent Magnet Elastomer (PME) Infused Soft Robot Skin for Tactile Sensing. 6039–6046. https://doi.org/10.1109/IROS51168.2021.9636817

[23] H-Y Song, J-H Lee, D Kang, H Cho, H-S Cho, J-W Lee, and Y-J Lee. 2010. Textile electrodes of jacquard woven fabrics for biosignal measurement. *The Journal of the Textile Institute* 101, 8 (2010), 758–770.

[24] Jessica Stanley, Katy Griggs, Oliver Handford, John A. Hunt, Phil Kunovski, and Yang Wei. 2022. Modular E-Textile Platform for Real-Time Sensing. In *Proceedings of the 2022 ACM International Symposium on Wearable Computers (ISWC '22)*. Association for Computing Machinery, New York, NY, USA, 131–135. https://doi.org/10.1145/3544794.3560293

[25] Jessica Stanley, John A. Hunt, Phil Kunovski, and Yang Wei. 2022. A review of connectors and joining technologies for electronic textiles. *Engineering Reports* 4, 6 (2022), e12491. https://doi.org/10.1002/eng2.12491

[26] Ryo Takahashi, Takuya Sasatani, Fuminori Okuya, Yoshiaki Narusue, and Yoshihiro Kawahara. 2018. A Cuttable Wireless Power Transfer Sheet. *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.* 2, 4, Article 190 (Dec. 2018), 25 pages. https://doi.org/10.1145/3287068

[27] Ryo Takahashi, Wakako Yukita, Takuya Sasatani, Tomoyuki Yokota, Takao Someya, and Yoshihiro Kawahara. 2022. Twin Meander Coil: Sensitive Readout of Battery-free On-body Wireless Sensors Using Body-scale Meander Coils. *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.* 5, 4, Article 179 (Dec. 2022), 21 pages. https://doi.org/10.1145/3494996

[28] Ryo Takahashi, Wakako Yukita, Tomoyuki Yokota, Takao Someya, and Yoshihiro Kawahara. 2022. Meander Coil++: A Body-scale Wireless Power Transmission Using Safe-to-body and Energy-efficient Transmitter Coil. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems* (New Orleans, LA, USA) *(CHI '22)*. Association for Computing Machinery, New York, NY, USA, Article 390, 12 pages. https://doi.org/10.1145/3491102.3502119

[29] Granch Berhe Tseghai, Benny Malengier, Kinde Anlay Fante, Abreha Bayrau Nigusse, and Lieva Van Langenhove. 2020. Integration of conductive materials with textile structures, an overview. *Sensors* 20, 23 (2020), 6910.

[30] Christiaan H Vinkers, Renske Penning, Juliane Hellhammer, Joris C Verster, John HGM Klaessens, Berend Olivier, and Cor J Kalkman. 2013. The effect of stress on core and peripheral body temperature in humans. *Stress* 16, 5 (2013), 520–530.

[31] Qi Wang, Yuan Zeng, Runhua Zhang, Nianding Ye, Linghao Zhu, Xiaohua Sun, and Teng Han. 2023. EmTex: Prototyping Textile-Based Interfaces through An Embroidered Construction Kit. In *Proceedings of the 36th Annual ACM Symposium on User Interface Software and Technology* (San Francisco, CA, USA) *(UIST '23)*. Association for Computing Machinery, New York, NY, USA, Article 20, 17 pages. https://doi.org/10.1145/3586183.3606815

[32] Irmandy Wicaksono, Carson I. Tucker, Tao Sun, Cesar A. Guerrero, Clare Liu, Wesley M. Woo, Eric J. Pence, and Canan Dagdeviren. 2020. A tailored, electronic textile conformable suit for large-scale spatiotemporal physiological sensing in vivo. *npj Flexible Electronics* 4, 1 (April 2020), 1–13. https://doi.org/10.1038/s41528-020-0068-y

[33] Heidi Woelfle, Olaitan Adeleke, Niharikha Subash, Alireza Golgouneh, Brad Holschuh, and Lucy E. Dunne. 2023. Plug-and-Play Wearables: A Repositionable E-Textile Garment System to Support Custom Fit for Lower-Limb Rehabilitation Applications. In *Adjunct Proceedings of the 2023 ACM International Joint Conference on Pervasive and Ubiquitous Computing & the 2023 ACM International Symposium on Wearable Computing (UbiComp/ISWC '23 Adjunct)*. Association for Computing Machinery, New York, NY, USA, 304–309. https://doi.org/10.1145/3594739.3610785

[34] Tomoyuki Yokota, Yusuke Inoue, Yuki Terakawa, Jonathan Reeder, Martin Kaltenbrunner, Taylor Ware, Kejia Yang, Kunihiko Mabuchi, Tomohiro Murakawa, Masaki Sekino, et al. 2015. Ultraflexible, large-area, physiological temperature sensors for multipoint measurements. *Proceedings of the National Academy of Sciences* 112, 47 (2015), 14533–14538.