Intelligent Soft Wearables

Integrating Imperceptible Interfaces

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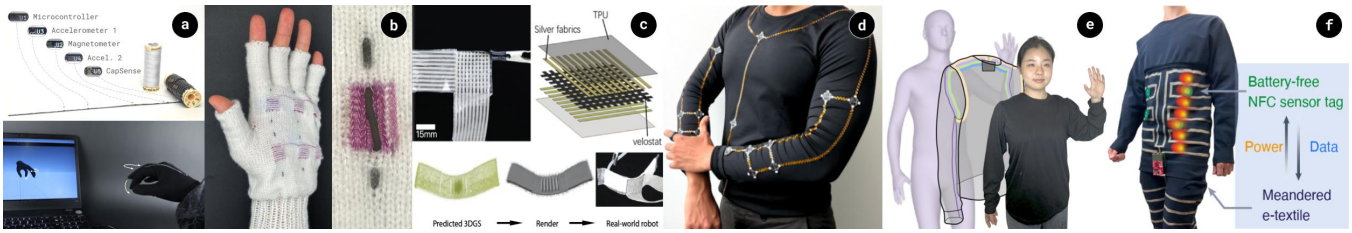

Figure 1: Showcasing a range of intelligent soft wearables across scales: (a) Integrated Circuits inside fibers, (b) magnetoactive textile modules enabling sensing and haptics, (c) tileable tactile sensor patches with flexible grid electrodes for wearables or robotics, (d) stretchable circuit network for electronic textile systems with distributed sensor nodes, (e) conductive yarns into seams for posture sensing, and (f) meander coils in clothing for wireless sensing.

Abstract

Human bodies are almost always in contact with soft materials like clothing, for warmth, protection, self-expression, etc. Recent advancements in intelligent soft wearables have augmented these on-body soft objects with computational functions and intelligence with little compromise on the softness and comfort of wearables, allowing prolonged wear. These innovations, which combine advanced soft sensor and actuator design, fabrication, and computational power, offer unprecedented opportunities to improve our health, productivity, and overall well-being with monitoring, actuation, and assistive capabilities. However, the inherent physical properties of soft materials present unique challenges in achieving practical interactions. The complexity of intelligent soft wearables, multiplexing intricate designs, soft materials, flexible electronics, advanced signal processing algorithms, and machine learning models, necessitates collaborative efforts from experts across diverse domains. This workshop aims to bring together interested researchers and practitioners across relevant domains to discuss the challenges and opportunities of intelligent soft wearables.

CCS Concepts

• **Human-centered computing**;

Keywords

Wearables; Soft Technologies; Applied Machine Learning; e-Textiles; Personal Fabrication; Sensing; Actuation; On-body Soft Robotics

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1 Introduction

The comfortable and conformable nature, essential factors in wearables' adoption or abandonment [1, 7], of soft wearables affords practical and prolonged uses of interactive interfaces [5, 24, 26, 27, 30, 31, 40], behavior monitoring and learning systems [18, 32, 34, 41, 45, 46], assistive wearables [16, 20], human augmentation [15], and entertainment [6, 9, 12, 13, 22, 37], with great potential in space [11], AR/VR [10], healthcare, and robotics, among other applications. Powered by advanced machine learning techniques, these intelligent wearables, serving as sensing and actuation interfaces, unobtrusively extract information and generate optimal feedback.

Compared with rigid wearables (*e.g.*, smartwatches and smart glasses), soft wearables (*e.g.*, textiles, silicone rubber) offer the benefits of conformability and comfortable large area coverage, but pose additional obstacles. For example, soft sensors suffer from hysteresis, detachment, and permanent deformations due to wear and tear. Similarly, soft actuators face difficulties due to the need for robust design and close coupling with the substrate of interest (such as the skin) to provide effective feedback. Actuation in soft interfaces is particularly challenging as it requires a delicate balance between maintaining the desired softness for comfort and conformability while providing sufficient strength to deliver effective and reliable performance. Despite recent advances in material science [8, 47], digital fabrication [17, 21], electronics miniaturization [25, 28, 35], and applied machine learning [43, 44] that have enabled exciting intelligent soft wearable applications, critical research challenges (detailed in Section 3) still lie ahead for everyday adoption of such systems by everyone. Addressing these human-centered challenges requires collaborative efforts from the design, scientific, and engineering communities as the design, fabrication, and application of intelligent soft wearables generally require domain-specific knowledge and cross-disciplinary integration [33].

At UIST 2024, we organized a successful workshop[1] on democratizing intelligent soft wearables [14] and attracted more than 40 attendees with diverse technical backgrounds. At UbiComp/ISWC 2025, we organized a 2nd successful workshop[2] also on intelligent soft wearables [42] with attendees from even more diverse technical backgrounds. Carrying forward the momentum, in this workshop, we would like to re-invite the UbiComp/ISWC community to merge expertise in a wide range of areas from technical HCI and design to technology acceptance. We aim to make this workshop serve as a platform to identify the challenges and opportunities for intelligent soft wearables research and foster collaboration.

2 Workshop Objectives

The goals and expected outcomes of our workshop include:

- Gathering researchers in relevant fields to share their findings, practices, and insights and showcase demos and Work in Progress (WIP);
- Discussing the grand challenges in designing, implementing, evaluating, and deploying intelligent soft wearables;
- Promoting intelligent soft wearables to the UbiComp/ISWC community;
- Fostering collaboration among researchers from various fields to enrich the research on intelligent wearable devices for HCI through diverse perspectives; and
- Planning for future events on related topics.

3 Workshop Topics: Opportunities and Challenges in Intelligent Soft Wearables

Topics of interest for this workshop include all aspects of soft intelligent wearables, from the design & implementation to applications and social acceptance & adoption. The workshop topics include (but are not limited to):

- **Trade-Offs between Functionalities and Softness/Wearability:** Designing intelligent soft wearables involves navigating trade-offs between maximizing functionality and preserving softness and wearability.
- **Individual Differences → Generalization&Personalization:** Humans have a wide range of body sizes and shapes, movement patterns, perceptions, physiological responses, behavior patterns, etc, making it difficult and unreasonable for universal generalization, given individual differences. Customization and/or calibration are often required to tailor to individual needs.
- **Closed-Loop Control with Sensors and Actuators:** Closed-loop control systems enable real-time dynamic interactions with the user: the sensors continuously monitor users' intent and/or status to adjust the actuators' behaviors (*e.g.*, haptic or compression feedback) [19, 23, 38].
- **Scalable Design, Manufacturing & Sustainability:** Scalable design and manufacturing methods [29] with sustainability for soft wearables are critical for widespread adoption. Scaling up for everyday, everywhere use brings sustainability concerns to the forefront [2–4]. Wearable waste, including e-waste from electronic devices and conventional clothing waste (e.g., cotton), already contributes significantly to global environmental challenges [36].
- **Deployment for Large-Scale Long-Term Evaluation:** Towards everyday adoption by everyone, large-scale long-term deployment for evaluation is crucial for evaluating intelligent soft wearables in diverse contexts and probing usability [39]. Different from rigid wearable devices, there are many technical challenges to enabling such deployments.
- **Soft Wearable Ecosystem: Single-Purpose vs. Generic One-for-All:** As the community envisions and invents the future soft wearable ecosystem, one key form-factor and interaction consideration is the number of devices in the ecosystem: how many wearables should one own and wear at a time?

4 An Estimate of Expected Attendance

As in previous years, we expect to welcome 30-50 attendees interested in intelligent soft wearables and related topics. When we organized the previous workshop at UIST 2024 and UbiComp 2025, about half of the attendees brought demos without formal solicitation, so we expect 15-30 demos to be showcased. We will run an open workshop and do not cap the number of attendees, as long as the venue allows, to generate rich discussions among the attendees.

[1] https://softwearables.github.io/uist24/
[2] https://softwearables.github.io/ubicomp25/

5 Workshop Plan

5.1 Pre-Workshop Preparation

5.1.1 Call for Demos & Reports & Papers. Please see our website[3].

5.1.2 Demo & Reports & Paper Selection and Publication. All the proposals will be submitted and reviewed through Precision Conference system (PCS). The review process will be light: each submission will have 2 reviewers who are part of the organizing committee.

5.1.3 Call for Participation. We will advertise for this open workshop participation, not only within the UbiComp/ISWC community but also within other HCI and AI venues via emails and social media. A webpage and repository were created to help promote, organize and document this workshop, along with the previous ones[12]: https://softwearables.github.io/.

5.2 Day of the Workshop

We plan for a half-day workshop format.

Opening Session (10 minutes). The workshop will commence with a brief opening session to introduce the agenda and objectives.

Keynotes (1 hour). We plan to invite 2 keynote speakers in the field to present for 30 minutes. They will talk about insights into the latest advancements and future trends in intelligent soft wearables.

Participants Introduction (30 minutes). All participants will briefly use 1 slide to introduce their research, with a shared Google Slides presentation which we will send out 1 week before the workshop. These slides will also be used to organize the 2 groups.

Demo and Poster Session (2 hours). All the demos and posters, both solicited submissions and informal demos brought by the attendees, will be divided into 2 groups so that all the participants have a chance to interact with others. General attendees will be encouraged to join any group session to engage in discussion and explore the demos and posters. This format aims to promote collaboration, inspire new ideas, and facilitate networking among researchers, designers, and practitioners in the HCI field.

Open Discussion on Challenges and Opportunities (20 minutes). This session will conclude with discussions built on the previous sessions to exchange ideas and experiences. Organizers will provide discussion topics and research questions that touch upon critical aspects of Intelligent Soft Wearables: focusing on challenges and opportunities. The workshop will then conclude with a summary of key takeaways, and next steps for fostering collaborations.

5.3 Post-Workshop Follow-up

The summary of key takeaways and next steps will be documented on our workshop website to openly share with a broader audience.

6 The Organizers' Backgrounds

Cedric Honnet is a PhD student at the MIT Media Lab focusing on HCI and advanced manufacturing. With a background in embedded systems, his research explores scalable electronic miniaturization for conformable wearables.

[3]https://softwearables.github.io/

Tianhong Catherine Yu is a PhD student at Cornell University, USA. Her current research is on scalable and practical AI-powered smart clothing and textiles for human-computer interaction.

Ryo Takahashi is a Project Assistant Professor at the University of Tokyo, Japan. His research focuses on electronic textiles capable of full-body wireless power and data transmission.

Tingyu Cheng is an Assistant Professor at the University of Notre Dame, USA. His current research is on building scalable and sustainable edge devices for human-computer interaction.

Cheng Zhang is an Assistant Professor at Cornell University, USA. His research focuses on integrating human-centered AI with advanced sensing technologies to empower everyday wearables in comprehending human behavior in real-world environments, with the goal of better supporting users.

Yoshihiro Kawahara is a Professor at the University of Tokyo, advancing IoT sensing with ubiquitous wireless power transfer, ultra-low-power wearable computing, and instant inkjet circuits.

Yiyue Luo is an Assistant Professor at the University of Washington's Department of Electrical & Computer Engineering, USA. Her research interests lie at the intersection of digital fabrication, human-computer/robot interaction, and applied machine learning.

Irmandy Wicaksono is an Assistant Professor at the Division of Industrial Design, National University of Singapore. His research focuses on integrating electronic devices into soft materials for applications spanning physiological sensing, human-computer interaction, interactive arts, architecture, and beyond.

Joseph Paradiso is a Professor at the MIT Media Lab. His research covers wireless sensing systems, wearable and body sensor networks, sensor systems for built and natural environments, energy harvesting, ubiquitous computing, space-based systems, and interactive music/media.

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