On-Demand Digital Fabrication and Computational Design Method for E-Textile

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Integration?

1. Fabrication: Textiles and electronic components
2. Design (an automated design approach):
   - Energy level
   - Self-powered e-textile
   - Multi-scale and multi-material

Fabrication and Design are interdependent:
Fabrication constraints the design
Design enables fabrication
1. Fabrication: Development of Fabrication Technologies for E-textiles

**Belt-in**
- Ease of implementation
- Accessories with fewer consideration of stretchability

**Adhere/Glue**
- Flexible and Stretchable
- Weak Bonding

**Sew-in**
- Interlocking network of threads
- Large deformation
- Fabrication

**Integration level of E-textiles**

- **What’s ongoing and what’s next??**
  - Fully compatible the garment industry (weaving, knitting, etc.)
  - **Adapt the pros of fabric:**
    - Soft, soft, conformal to body shape, washable…
  - Scalable

**A wearable Electronic heating device**

**A hybrid flexible electronics**

**Electronic devices embedded into knitted fabric**
(Wicaksono et al. 2020)
1. Development of Fabrication Technologies for E-textiles

What’s Next: Digital Fabrication Technologies e.g., conformal weaving

A method to design and weave a conformal flexible electronics on surface

Manufacturing:

- **2D-printable electronics**: more reliable, efficient, and economical.
- Surface **shaped directly** during weaving: no stretching, bending only

Method:

- Threads: dense **without self-intersection**
- **Automatic pipeline** suits for surfaces of various topologies

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The interconnection between design problems and performance in E-textiles

How to intelligently design to achieve better performance?

- Computational Tools: Multi-physics simulation + Computational design (e.g., TopOpt + AI)

Device position
Topology/Size/Dimensions
Connectivity
Fabrication

Device position
Power
Topology/Size/Dimensions
Connectivity
Fabrication

Power
Thermal
Durability/Comfortableness
Weight
Functionality

Functionality

Power

Design Components:

Performance Evaluations:

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Plus: the design components interact with each other as well.
Learning loop for robust-automated design

Design optimization

- Objectives
  - Performance
  - Manufacturability

Sensitivities

Update design

Parameter and loading condition distributions
Computational Models/ Upscaled constitutive models

Experiments Validation and data acquisitions
2. Design Problem 1: Improve the Integration Level of Energy Consumption

Design a Self-powered E-textile system

**Energy Harvesting from body movement**

- Flexible Piezoelectric Nanogenerators (PENGs)
- Flexible Triboelectric Nanogenerators (TENGs)

**Printed battery**

- Design considerations:
  - Manufacturing constraint: e.g., ability to be printed
  - Flexible

Current challenges:
1. Understand the multi-physics problem
2. Automated design

- Ceramic Li-ion conductor
- Polymer Li-ion conductor
- Carbon (electronic conductor)

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Ryan R. Kohlmeyer et al. [https://pubs.rsc.org/en/content/articlelanding/2016/TA/C6TA07610F](https://pubs.rsc.org/en/content/articlelanding/2016/TA/C6TA07610F)

Tural Khudiyev et al. [https://doi.org/10.1016/j.mattod.2021.11.020](https://doi.org/10.1016/j.mattod.2021.11.020)
3. Design Problem 2: Improve the Integration Level of Multi-material and Multi-scale

- Challenges and limitations: reliability under large deformation, fabrication cost
- Opportunity: e.g., Topology Optimization

Textile Design

- Schematic of optimized flexible electronics design on a human face surface

E-textile: a multi-material and multi-scale

- Rigorous homogenization:
  - upscale nonlinear equations with guarantees

A Symbolic Upscaling from the cell-scale to the battery pack-scale (DARPA-CompMods)

Structural Design

- Challenges: cycling stability, nano-cracks, wrinkling due to the Poisson effect
- Opportunities:
  - Meta-material design:
  - Self sensing/active/ resilient: Active material

Interactive with the environment (Haptics)


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