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Advanced Textiles

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Textile-to-Electronics Interfaces: Engineering Next-Generation Wearables

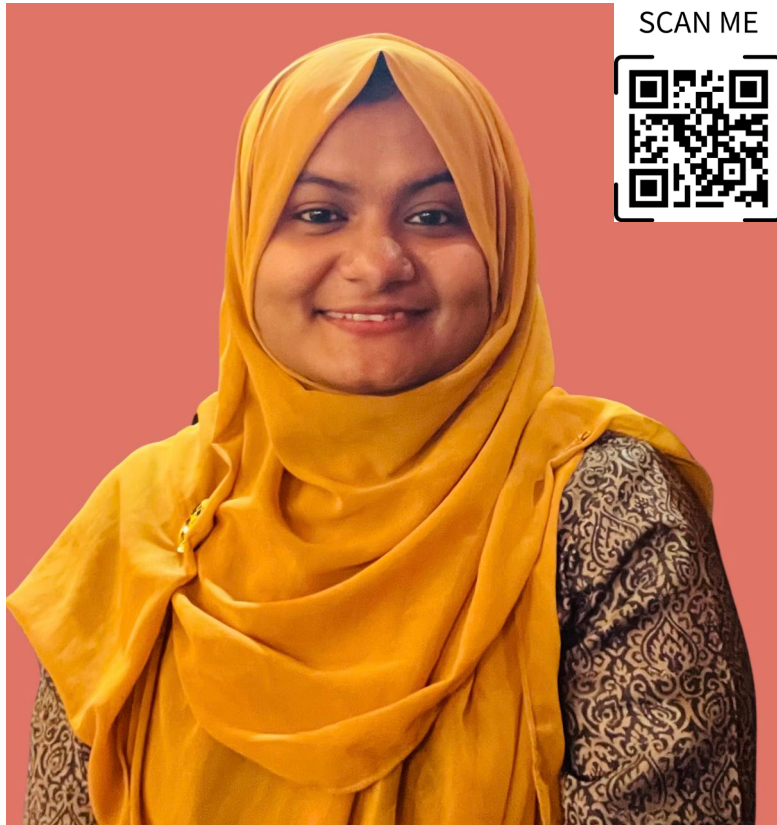
Ayesha Siddika

PhD Student, Fiber and Polymer Science,
Wilson College of Textiles, NC State University.

Advisor: Dr. Amanda Mills



About Me



AYESHA SIDDIKA

SCAN ME



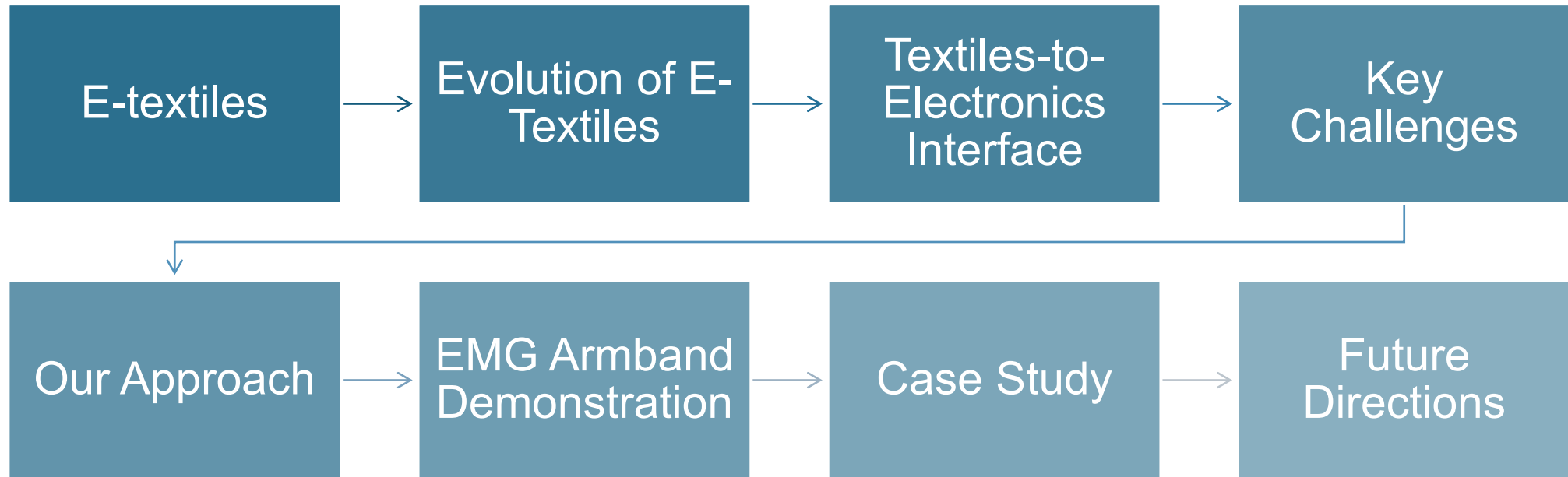
EDUCATION

- **PhD Student**, Fiber and Polymer Science (**minor** in Electrical and Computer Engineering); North Carolina State University (NCSU), Raleigh, USA
Supervisor: Dr. [Amanda Mills](#)
Dissertation Title: Design and Development of Flexible, Robust, and Reliable Interconnects for Next-Generation Textile-based Wearable Electronics
- **MS** in Design, Merchandising & Textiles; University of Wyoming (UW), Laramie, USA
- **BSc** in Textile Engineering (major in Fabric Manufacturing Engineering); Bangladesh University of Textiles (BUTEX), Dhaka, BD

WORK EXPERIENCE

- | | |
|--|-------------------|
| • Graduate Research Assistant – SHIFT Lab, NCSU | May 2024-Present |
| • Temporary Lecturer, University of Wyoming, USA | Jan 2023-May 2023 |
| • Graduate Research Assistant – University of Wyoming | Jan 2021-Dec 2022 |
| • Assistant Professor, Khulna University of Engineering & Technology, BD | Feb 2017-Dec 2020 |

Agenda



What is E-Textile?

- **Electronic textiles**, also known as **e-textiles**, are a subcategory of smart textiles and refer to **textiles** that have been **embedded with electronic components**, such as sensors, actuators, and conductive materials.
- These textiles have the **ability to sense and react** to their environment as well as collect data on applications.
- This makes them a unique and exciting innovation in the world of advanced technology.
- E-textiles can be classified into **two main categories**: those with **embedded classical electronic devices** (e.g., LEDs, batteries) and those with **electronics integrated directly** into the textile substrate through conductive or active fibers.



Electronic Textiles (E-Textiles)

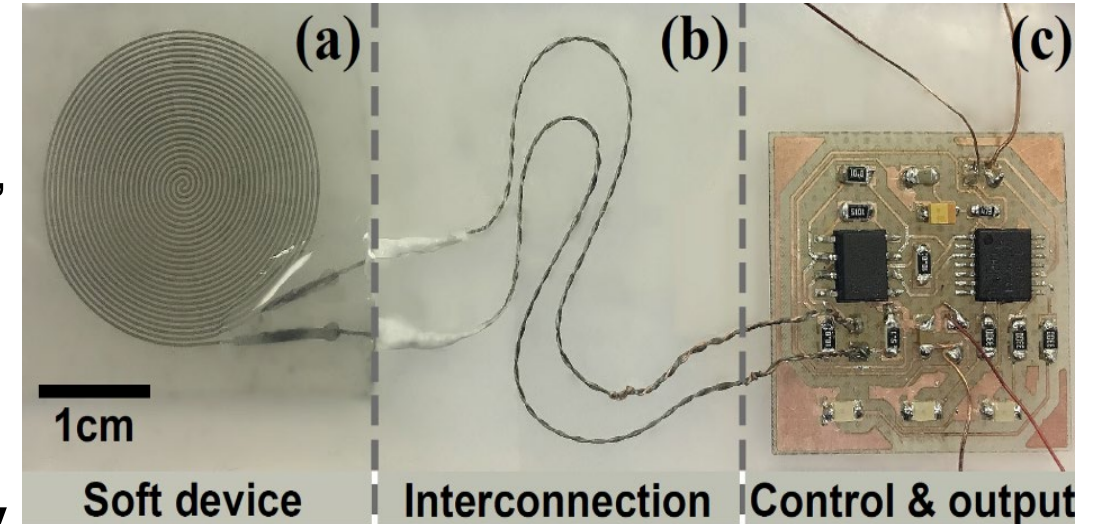


Evolution of E-Textiles

- **1960s-70s:** The first electronic textiles were developed by integrating conductive thread into fabric to create a simple circuit.
- **1980s:** E-textiles were introduced in the fashion industry, with designers experimenting with integrating technology into clothing.
- **1990s:** The first commercial electronic textiles, such as electro-luminescent T-shirts, were introduced to the market.
- **2000s:** The rise of wearable technology spurred significant growth in e-textile development, leading to the creation of smart clothing and fitness wearables.
- **2005:** Levi's introduces their first line of e-textiles with the "RedWire DLX" jean that incorporates lighting, sound, and connectivity.
- **2010:** The launch of the first smartwatch, the Pebble, sparked a new wave of innovation in wearable technology and e-textiles.
- **2015:** Google introduces Project Jacquard, a platform for creating interactive e-textile products.
- **2016:** The launch of the first commercial e-textile product incorporating flexible electronics, the Nike HyperAdapt 1.0 self-lacing shoes.
- **2018:** The development of washable, stretchable, and breathable e-textiles, bringing new possibilities for e-textile applications in healthcare and sports.
- **2020s:** The COVID-19 pandemic drives further innovation in e-textile development, with a focus on wearable devices for monitoring health and tracking disease spread. Multifunctional, washable, AI-integrated, and IoT-connected e-textiles for healthcare, sports, and fashion.

Textile-to-Electronics Interface

- Textiles-to-electronics refers to the **interface or connection zone between textile materials and electronic components**, where soft, flexible, and deformable textile structures meet hard, conductive, and often rigid electronic parts.
- It encompasses the **engineering strategies, materials, and integration methods** that allow electronic devices (such as sensors, circuits, or connectors) to be **physically attached, electrically connected, and mechanically stable** on or within textile substrates.
- It is the bridge that enables fabrics to become functional, interactive systems capable of sensing, actuating, communicating, or managing energy — turning conventional textiles into **electronic textiles (e-textiles)**.



Key Components

A. Textile Substrate

- Acts as the **foundation or host** for electronics.
- Can be woven, knitted, or nonwoven; often chosen for **flexibility, breathability, and comfort**.
- Must maintain performance under **bending, stretching, and washing**.

B. Interconnects (Conductive Pathways)

- Provide **electrical continuity** between sensors, power sources, and circuits.
- Require low resistance, mechanical resilience, and wash durability.

C. Attachment / Integration Mechanism

- The **junction** where the electronic component connects to the textile.
- Must manage the mismatch between **soft textiles** and **rigid electronics**.

D. Electronic Connectors / Modules

- Include **microcontrollers, power supplies, or communication units (Bluetooth, NFC)**.
- The challenge is to integrate them **without compromising flexibility, drape, or wearability**.

Interconnects

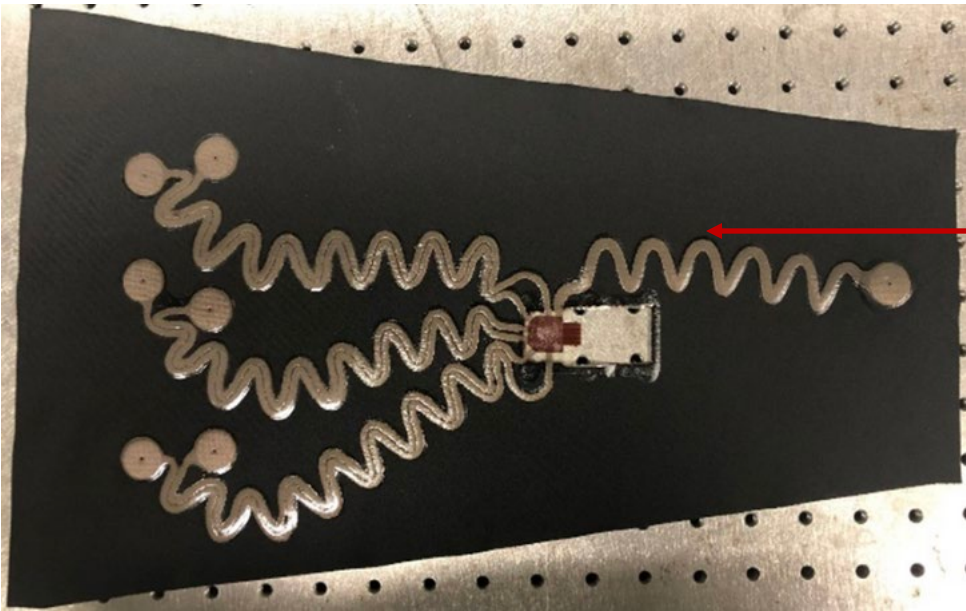
A wide range of interconnect technologies is used in electronic textiles (e-textiles), each with distinct advantages and limitations regarding flexibility, durability, and integration with textile substrates.

Interconnect Type	Key Features	Limitations
Conductive threads/yarns	Flexible, textile-like, washable (to a point)	Degrades with washing/mechanical
Printed/coated conductive layers	Customizable, scalable, flexible	Washability, adhesion challenges
Physical connectors (Snap)	Detachable, robust connection	Bulky, less flexible
Fiber/yarn-level integration	Highly flexible, experimental	Not yet commercialized

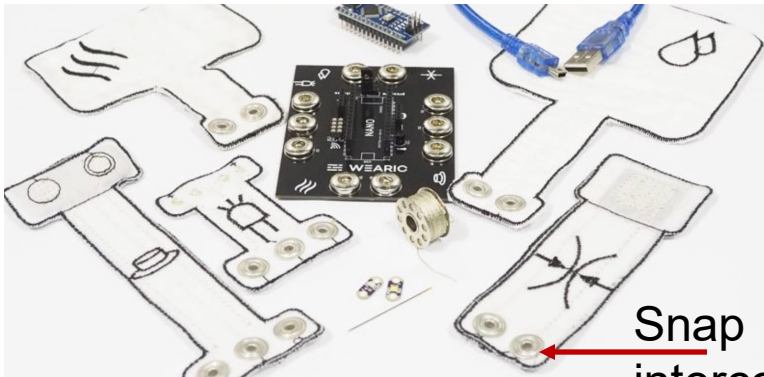
Interconnects



Conductive thread
interconnect



Printed
interconnect



Snap
interconnect



Cu wire woven
into fabric

Integration Mechanism

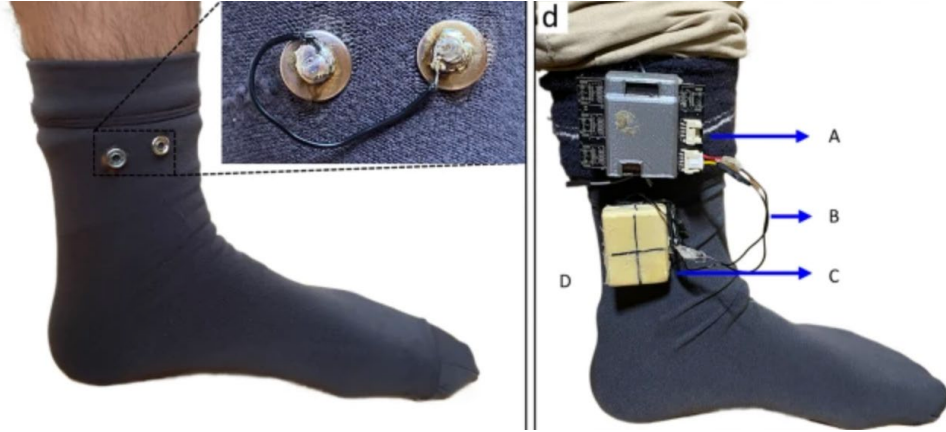
- Connecting the interconnect with the electrodes/sensors

Mechanism	Key Features	Limitations
Conductive Adhesives (Epoxy, ECA)	Flexible, moderate durability, low temp.	Limited stretchability, may degrade with washing, higher resistance than solder
Printed Conductive Inks/Pastes	Planar, scalable, compatible with textiles	Durability depends on ink/encapsulation, can crack or delaminate, limited stretchability
Non-Conductive Adhesive Bonding	Gentle, low temp, pressure-based contact	Less reliable for high current, can shift, moderate resistance, not for power applications
Conductive Stitching/Embroidery	Textile-like, flexible, scalable	May loosen over time, variable contact resistance, less robust to repeated stress
Mechanical Connectors (Snaps, Rivets, Magnetic)	Detachable, robust, easy replacement	Bulky, may affect comfort/aesthetics, can wear out, higher contact resistance
Soldering (Low-Temp, Direct)	Strong, low-resistance, robust	High temp can damage textiles, rigid, risk of short circuits, complex process

Electronic Connectors

Connector Type	Attachment System(s)	Features & Limitations
Snap/Snap Button Connectors	Mechanical snap fasteners, often with conductive pads	Detachable, robust, but can be bulky and may affect comfort
Magnetic Connectors	Embedded magnets with conductive surfaces	Repositionable, user-friendly, but may detach unintentionally
Pogo Pin/Clip Connectors	Spring-loaded pins or edge clips	Reliable multi-point contact, require precise alignment, can wear out
Conductive Stitching/Embroidery	Conductive threads/yarns stitched to pads	Textile-like flexibility, but may loosen or vary in resistance over time

Electronic Connectors



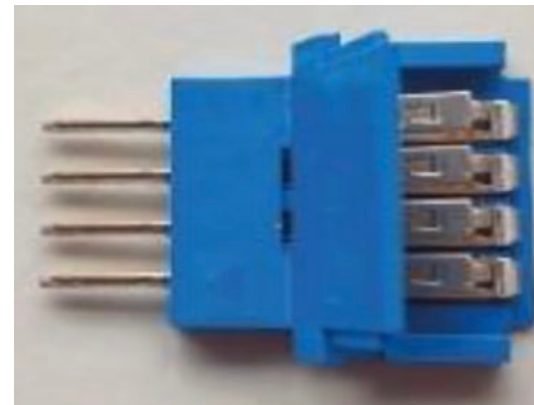
Snap Connectors



Magnetic Connectors



Pogo Pin



Pin Connector

Why does Interface matter?

- The textile-to-electronics interface is **the most critical and fragile part** of any e-textile system.
- Its performance directly determines **functionality, durability, comfort, and manufacturability**.
- For **health monitoring, rehabilitation, athletics, or military wearables**, the interface ensures **accurate sensing and signal integrity** even under movement or washing.
- A poorly designed interface leads to **signal noise, detachment, breakage, and device failure**.

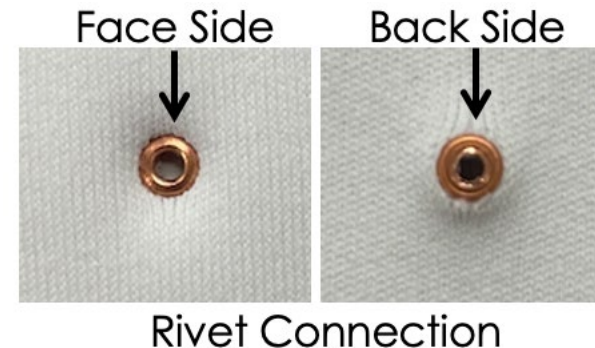
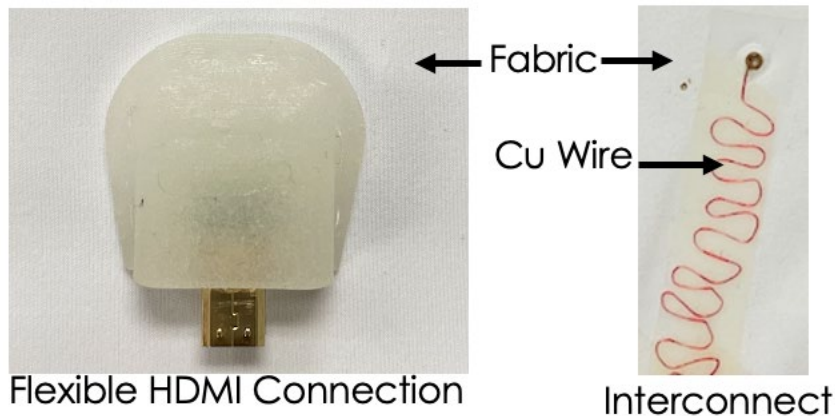
Key Challenges

- **Maintaining mechanical flexibility** while ensuring robust **electronic performance**.
- Achieving durable, repeatable electrical connections that **withstand daily wear** and **wash** cycles.
- Managing **interface failures** due to mechanical **mismatch or stress at junctions** between textiles and electronics.



Our Approach

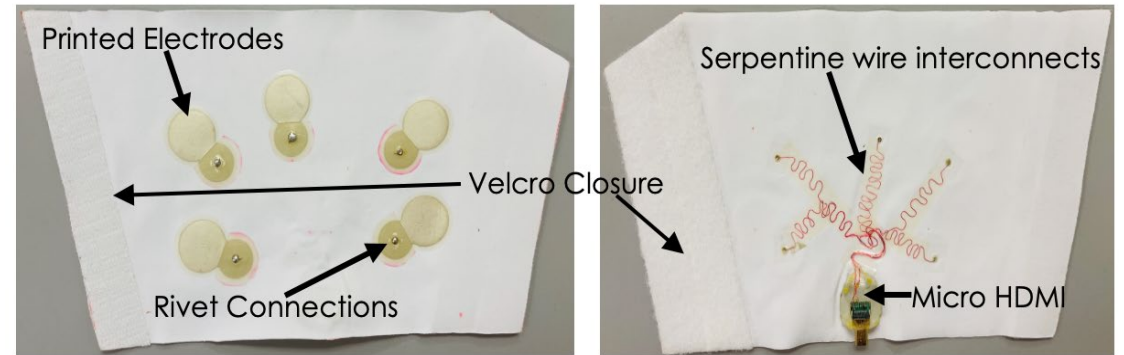
- **Serpentine Wire Interconnects:** Flexible paths that accommodate mechanical strain without breaking or losing conductivity.
- **Rivet Connection Points:** Mechanically strong and electrically stable, great for repeated use and textile deformation.
- **Robust HDMI Connectors:** Enable modular, high-bandwidth, reliable signal transmission in textile-based electronics.



EMG Armband Demonstration

A prototype EMG armband was fabricated using a rivet connection, a serpentine Cu wire interconnect, and a flexible micro-HDMI connector.

- Textile Substrate: White compression single jersey knit (82% polyester, 18% spandex, 260 gsm, 0.48 mm thick)
- Electrodes: 20 mm diameter dry electrodes, screen-printed Ag/AgCl ink on stretchable TPU.



EMG Armband

- Interconnects: A manual serpentine interconnect was made using copper wire.
- Rivet Connections: A 1.2 mm rivet attached and soldered at the wire-electrode junction; the joint protected with stiff TPU.
- Micro-HDMI: Semi-rigid casting resin is used to stitch the micro-HDMI to the textile substrate.

Data Collection Protocol

- **Armband Fit:** Electrode was placed parallel to the forearm extensor and flexor muscles; ground near the elbow. The armband was secured with Velcro; electrode-skin contact pressure was maintained at 1-1.5 kPa to ensure comfortable biopotential measurements.
- **Wash Cycle:** Three commercial washes (AATCC LP1 standard); air dry after each cycle.
- **Measurement Protocol:**
 - Alcohol wipes and light abrasion for skin preparation
 - Isometric grip task at 25% maximum voluntary contraction (MVC) with feedback
 - EMG collected at 3916 Hz using Sentimo wireless amplifier (Bluetooth to laptop).
- **Runs:** 5 runs per condition, 10 trials/run, 3-second contractions; before wash (T0) and after each wash (T1, T2, T3).

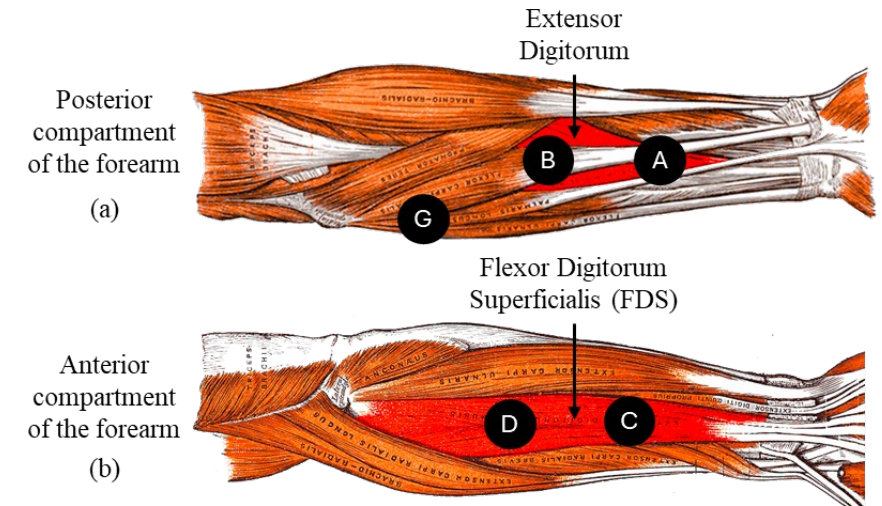
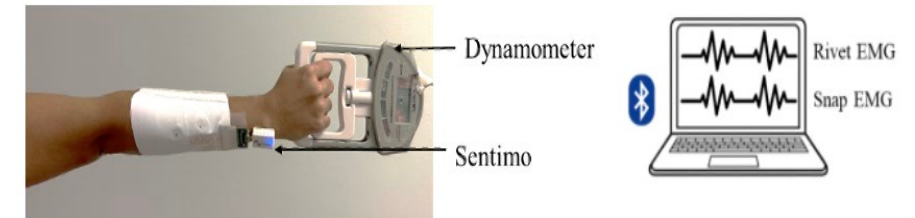


Figure. (a) Electrode placement on extensor digitorum (ED) muscle (A and B) and (b) flexor digitorum superficialis (FDS) (C and D), G represents ground (placed close to the elbow)



Durability Assessment of Rivet and Snap Connections for Wearable EMG Armband

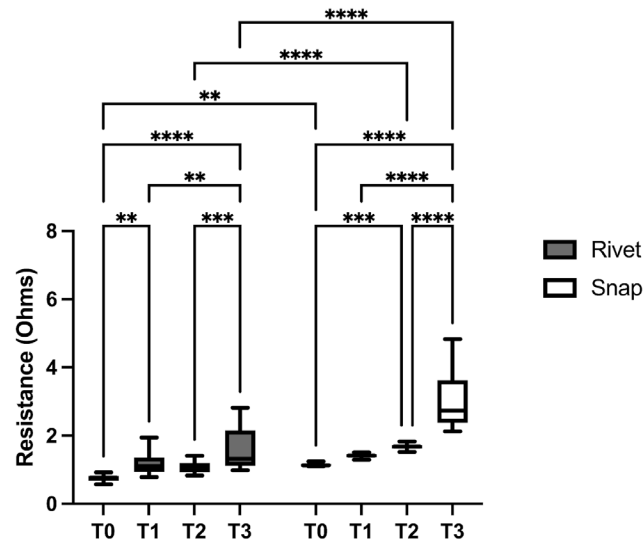


Figure. Resistance from the electrode to the connector before wash (T0) and after every wash cycle (T1, T2, T3 respectively) for snap and rivet armbands.

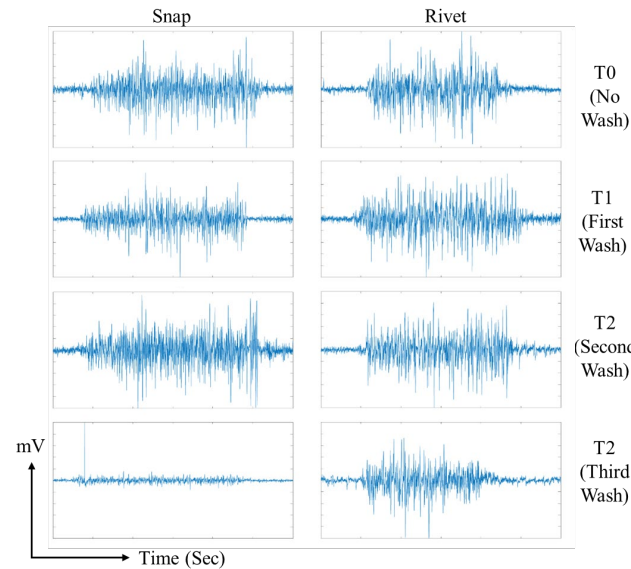


Figure. Normalized EMG signal from snap and rivet armband before (T0) and after each wash cycle (first wash, second wash, third wash is T1, T2, T3 respectively) for stationary condition.

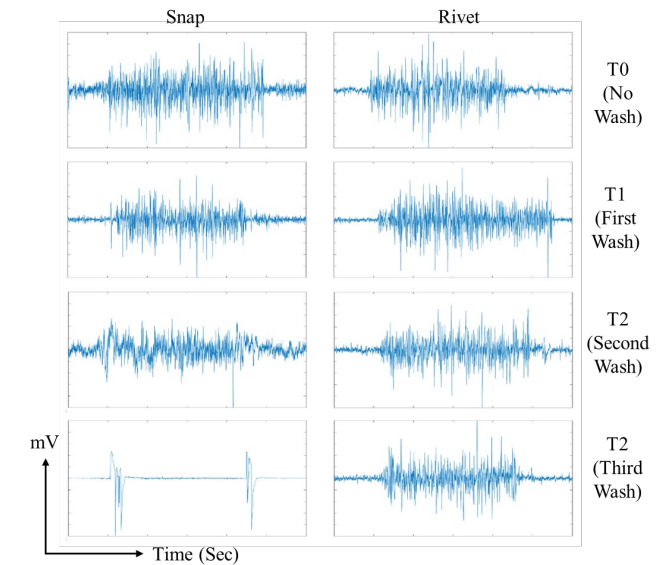


Figure. Normalized EMG signal from snap and rivet armband before (T0) and after each wash cycle (first wash, second wash, third wash is T1, T2, T3 respectively) for dynamic condition.

Findings

- **Rivet** connections provide **secure anchoring** of electronic modules onto fabric, **minimizing interface stress** and improving durability.
- **Serpentine copper wire interconnects** offer **enhanced compliance and resistance to fatigue** caused by bending or stretching, which is crucial for daily wear and movement.
- A **flexible micro-HDMI connector** enables the **modular attachment** of signal-processing hardware, facilitating easy upgrades or maintenance.
- Comparative analysis highlights the **improved performance** and durability of new textile-electronic interfaces.
- Real-time EMG demonstrations show low-noise signals and reliability during arm movements, supporting non-invasive health monitoring.

Broader Impact

- Integrating electronic components into flexible textiles will enable the broader adoption of comfortable, reliable wearable devices.
- It will enable the development of non-invasive health-monitoring systems, personalized rehabilitation tools, and early-disease-detection platforms, all of which can greatly enhance quality of life for diverse populations.

Future Work

- Explore connection strategies matching end-use requirements and expected mechanical loads.
- Use modular designs for scalable, multi-sensor smart textiles.
- Explore new applications in interactive and adaptive textiles.



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