FlexiSense: A Toolkit for Battery-Free Gesture Recognition via Garment Modification

Zhiqi Wang*
zhiqiwang@zju.edu.cn
Zhejiang University
Hangzhou, Zhejiang, China

Mengyan Sun*
995590382@qq.com
Zhejiang University
Hangzhou, Zhejiang, China

Zhihan Cao
hannahcao1230@gmail.com
Zhejiang University
Hangzhou, Zhejiang, China

Guanyun Wang†
guanyun@zju.edu.cn
Zhejiang University
Hangzhou, Zhejiang, China

Abstract

We present FlexiSense, a democratized toolkit designed to retrofit everyday clothing into battery-free interfaces for gesture recognition. Users can develop smart textiles by connecting and strategically placing relevant modules on garments, guided by detailed instructions. The system is self-powered by electromagnetic induction, harvesting kinetic energy from user movements. Gesture sensing relies on stretchable conductive fabrics, where resistance changes directly correspond to user actions. With low-power, multimodal outputs for closed-loop interaction, this toolkit democratizes the creation of self-powered interactive apparel, opening new avenues in wearable computing and human-computer interaction.

CCS Concepts

• **Human computer interaction → Human computer interaction(HCI)**; • **Interaction techniques**;

Keywords

On-device sensing, electronic textiles, design tools, sustainable energy sources, self-powered sensors, wearable computing

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1 Introduction

Battery-free smart textiles are a growing area in wearable computing, valued for their sustainability and convenience. By eliminating the need for batteries, these textiles reduce electronic waste and remove the burdensome cycle of recharging, offering a truly "wear-and-forget" experience that integrates seamlessly into daily life. This has driven significant research in human-computer interaction towards sustainable energy solutions. Many projects have explored self-powered energy sources like triboelectric nanogenerators [1, 2, 6, 14] and novel sensing techniques such as capacitive and electromagnetic induction for signal recognition [4, 7, 12]. This has led to the development of integrated systems that combine diverse interaction methods [9, 13]. Despite the promise of these self-powered smart textiles, their broader adoption by makers and designers remains limited. The complexity of current systems often hinders wider use, as their development processes frequently require inaccessible equipment or custom circuits, and critical components are often non-commercial. Furthermore, much of the existing research focuses on technical prototypes rather than the creation of user-friendly tools. In parallel, toolkits like Lilypad [3] and EmTex [11] have proven effective in lowering the fabrication barrier for e-textiles by providing modular and accessible components [5, 8]. However, the user-friendly toolkit approach has not been widely applied to the more complex domain of battery-free systems. These factors create a substantial technical barrier, preventing wider exploration and innovation in the field.

To overcome these challenges, we introduce FlexiSense, a customizable toolkit for creating battery-free gesture recognition interfaces from everyday clothing. Inspired by the success of modular e-textile toolkits, we adopt a similar approach to simplify the creation of integrated battery-free systems, enhancing their accessibility. Our approach simplifies self-powered textile fabrication by utilizing readily available materials and familiar crafting techniques like needlework. FlexiSense provides a complete set of self-powered sensing and multi-modal interaction modules, guiding users to integrate these functionalities into their garments. We believe this "retrofit" method will empower a broader range of creators, driving diverse innovations in wearable computing.

2 Battery-Free Powering and Recognition Mechanism

Drawing upon Faraday's law of electromagnetic induction, we developed a energy harvesting system integrated into a bracelet. It incorporates 30 NdFeB permanent magnets, each 10mm in diameter and 3mm thick, externally enveloped by a 1500-turn copper coil assembly (Fig. 2a). During wrist movements, the coil cuts magnetic

*Both authors contributed equally to this research.
†Corresponding author

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flux lines, generating alternating current (AC) which is then rectified to 80-400 mV direct current (DC). A CJMCU-25570 energy harvesting module continuously captures energy when the voltage exceeds 100mV, boosting it to a stable 5V output. This robust power supply supports subsequent sensing and signal processing modules.

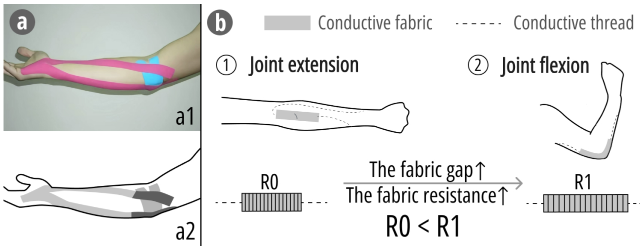

Figure 1: (a) We adapted the intramuscular patch method (a1) — used for golfer's elbow — to optimize conductive fabric placement (a2); (b) Gesture recognition pipeline.

Our action recognition relies on resistance changes in stretch-sensitive conductive fabric, driven by limb motion. To enhance elbow movement detection, we adopted a kinesiology tape-inspired strapping method commonly used for medial epicondylitis [10], identifying two optimal placement sites. As shown in Fig. 1, a 5cm x 1cm strip of fabric exhibits 5M resistance when the arm is extended, rising to 20M when flexed. A custom Digispark board based on the ATTINY85 reads voltage variations from these states.

3 FlexiSense Toolkit

3.1 Modular Components

It includes four integrated modules for intuitive assembly (Fig. 2a). **Power Module** integrates a flexible bracelet housing a circular array of NdFeB permanent magnets. A rotatable coil assembly is mounted on the bracelet, positioned to cut the magnetic flux lines during relative movement against the magnets. For easy integration, the coil module features convenient pin connections. It allows natural wrist movements to power the system without batteries.
Signal Module is a wrist-worn board unit with a central PCB. It first uses a boost converter to stabilize the voltage from Power Module, then processes signals from textile's resistance changes. Three pre-programmed pin types are reserved for flexible output options, enabling user customization. The module also integrates conductive fabric made by coating ice silk-threaded fabric with carbon ink, which can be placed at desired locations to detect gestures.
Output Module provides three low-power modules for user feedback, enabling multimodal interaction. These include: (i) a bistable e-ink display for persistent, low-power visual output, (ii) a miniature vibration motor for discrete haptic feedback, and (iii) a compact speaker for auditory cues. The selection of these components was specifically driven by their minimal power consumption to ensure stable operation solely from Power Module.
Connection Module uses conductive thread and a standardized system of metallic snap fasteners to create robust, user-friendly electrical connections between modules. Each module's connection port has a pre-soldered male snap component. Users simply secure the conductive thread to a female snap and fasten it to the male port, establishing a reliable electrical connection.

3.2 Workflow and Fabrication Guidance

It includes documentation to guide prototyping workflows (Fig. 2b). **Power System Assembly** initiates the workflow. Users connect the Power Module's rotatable coil to the power input port of Signal Module's wrist-worn board using the provided conductive thread and snap fasteners, enabling the coil to power the circuit board.
Textile Sensor Integration links physical actions to digital signals. Users cut conductive fabric to a specified length (e.g., a 5 cm strip) and integrate it onto target locations, such as a joint. The fabric is then sewn onto the clothing with conductive thread, routing the thread to the wrist area. The other end of the thread is then connected to the Signal Module's input via a snap fastener.
Output Module Connection provides customizable feedback. Users can choose visual, haptic, or auditory modules, each mapped to specific pins on the wristband as guided. Modules connect via conductive thread and snaps to designated pins. (Note: The e-ink display is limited to the wristband due to pin constraints.)

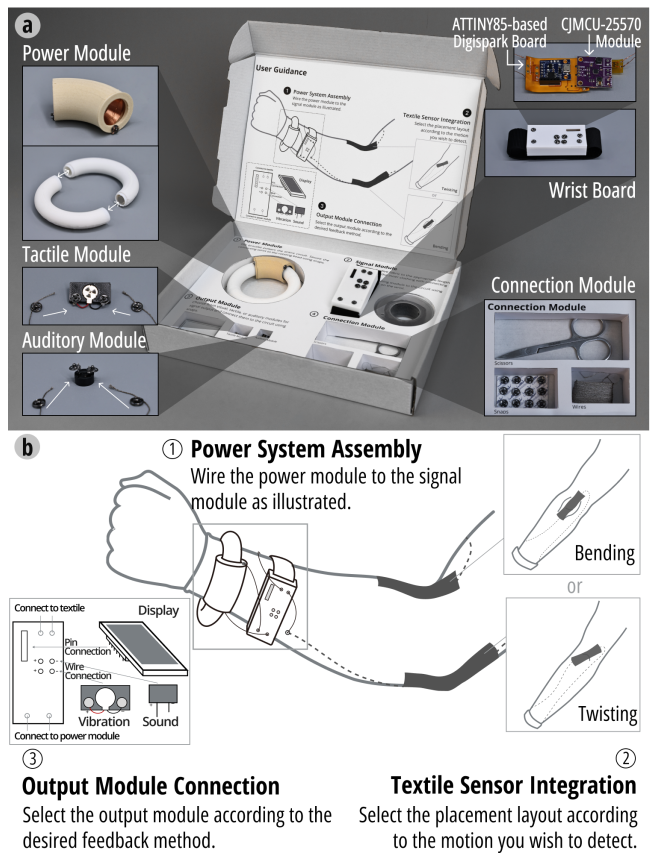

Figure 2: Modular components and guidance of FlexiSense.

4 Applications

The practical utility of the toolkit is demonstrated through two primary applications in personal health and fitness.

Real-time Posture Correction It enables the creation of self-powered devices for real-time posture correction. These devices seamlessly integrate into daily life, providing haptic feedback (like vibration alerts) when a user's posture deviates from a pre-defined correct state, all without needing an external power source.

Training with Repetition Counting It facilitates assisted training with repetition counting. Users can develop bespoke counters for various fitness goals by defining target motions and integrating textile sensors at key anatomical locations, such as the knee for counting high-kicks or the elbow for tracking lifting exercises.

5 Conclusion & Future work

This poster presents our ongoing toolkit, FlexiSense, enabling battery-free gesture recognition via garment modification. Our approach aims to simplify smart textile creation by leveraging self-powering through electromagnetic induction and gesture sensing via stretchable conductive fabrics. As FlexiSense is an initial toolkit, a wider range of output modules and expanded gesture sets are required to offer greater customization, potentially through user-editable code blocks. Additionally, we plan to conduct extensive user studies to rigorously validate the feasibility and impact of this method.

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