Full-body WPT: wireless powering with meandered e-textiles

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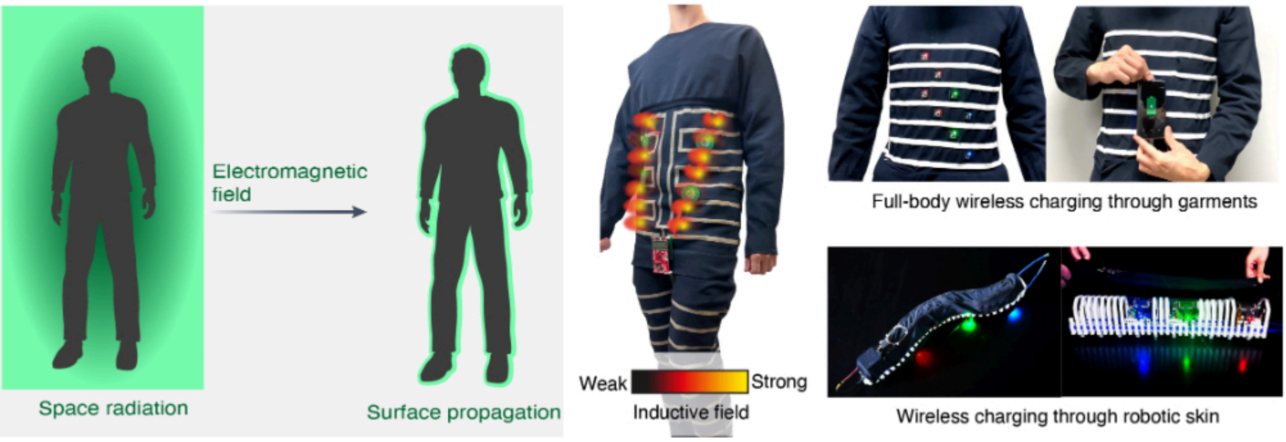

Abstract: We present Full-body WPT, wireless power networking around the human body using a meandered textile coil. Unlike traditional inductive systems that emit strong fields into the deep tissue inside the body, the meander coil enables localized generation of strong magnetic field constrained to the skin surface, even when scaled to the size of the human body. Such localized inductive system enhances both safety and efficiency of wireless power around the body. Furthermore, the use of low-loss conductive yarn achieve energy-efficient and lightweight design.

Tags: HCI Device, Hardware, Wireless

1 Introduction

Wearable and implantable devices are playing an increasingly important role in health monitoring, fitness, and human–machine interaction *(Negra et al., 2016)*. However, powering these devices remains a major challenge. Batteries are bulky, need frequent charging, and limit usability for continuous or long-term operation *(Lin et al., 2022; Tian et al., 2019)*.Wireless power transfer is a promising alternative, but most existing systems either produce unwanted electromagnetic fields around the body or fail to safely deliver high power *(Takahashi et al., 2022)*.

We introduce a wireless power network integrated into clothing, using two-dimensional meander coils. These coils follow a zigzag pattern that reverses direction with each turn, allowing magnetic fields to stay close to the skin even when scaled to full-body size. Our system uses either liquid metal *(Sato et al., 2025; Takahashi et al., 2022)* or conductive fiber *(Takahashi et al., 2025; Takahashi, Yukita, Sasatani, et al., 2022)* as the conductor of the textile meander coil, achieving both stretchability and energy efficiency. This high performance allow for continuous power delivery across the entire body without sacrificing comfort or mobility. Full-body WPT enables new applications such as full-body sensing suits *(Takahashi et al., 2025; Takahashi, Yukita, Sasatani, et al., 2022)*, distributed haptic feedback *(Sato et al., 2025; Takahashi, Yukita, Yokota, et al., 2022)*, and scalable robotics *(Kanada et al., 2025)*.

2 Related work

Various approaches have been explored for wirelessly powering on-body electronics, including far-field radio frequency (RF) radiation *(Luo et al., 2018; Tian et al., 2023)*, capacitive coupling, and near-field magnetic coupling *(Lin et al., 2022; Takahashi et al., 2018)*. RF-based systems using antennas can deliver power over longer distances, but they suffer from low efficiency when targeting small, body-mounted devices, and raise safety concerns due to radiation exposure to the dielectric body. Capacitive coupling used in body-coupled communication (BCC), leverages the human body as a transmission path for electric fields. While effective for data transmission, capacitive systems are highly sensitive to grounding conditions and body posture, and typically deliver very limited power due to the safety *(Takahashi et al., 2018)*.

In contrast, magnetic coupling via coils offers a more stable and efficient method for on-body power transfer. Magnetic fields are less affected by the body's dielectric properties and can be confined to the surface, reducing energy loss and unintended exposure. Prior work has explored magnetic resonant coupling and wearable coil arrays *(Li et al., 2021; Takahashi et al., 2018)*, but these systems often rely on rigid components or heavy materials like liquid metal, limiting wearability. Our work builds on this foundation by using flexible, planar meander coils that maintain magnetic efficiency while enabling lightweight, body-scale integration. This allows for continuous power delivery over large areas of the body without sacrificing safety or comfort.

3 System design

The key component of our wireless power system is a two-dimensional meander coil, designed to generate magnetic fields confined to the skin surface (see Figure 1 a). The meander coil consists of a serpentine-shaped conductor, in which the current direction alternates with each turn *(Takahashi, Yukita, Sasatani, et al., 2022; Takahashi, Yukita, Yokota, et al., 2022)*. This alternating pattern creates adjacent loops with opposing circulation, resulting in a net magnetic field that is reinforced in the direction parallel to the coil plane and concentrated near the surface. Unlike traditional circular or spiral coils that generate broad magnetic fields extending into the surrounding space, the meander layout promotes near-field localization, making it suitable for operation close to the body. This geometry minimizes stray field leakage and enhances coupling between coils placed on different parts of the body.

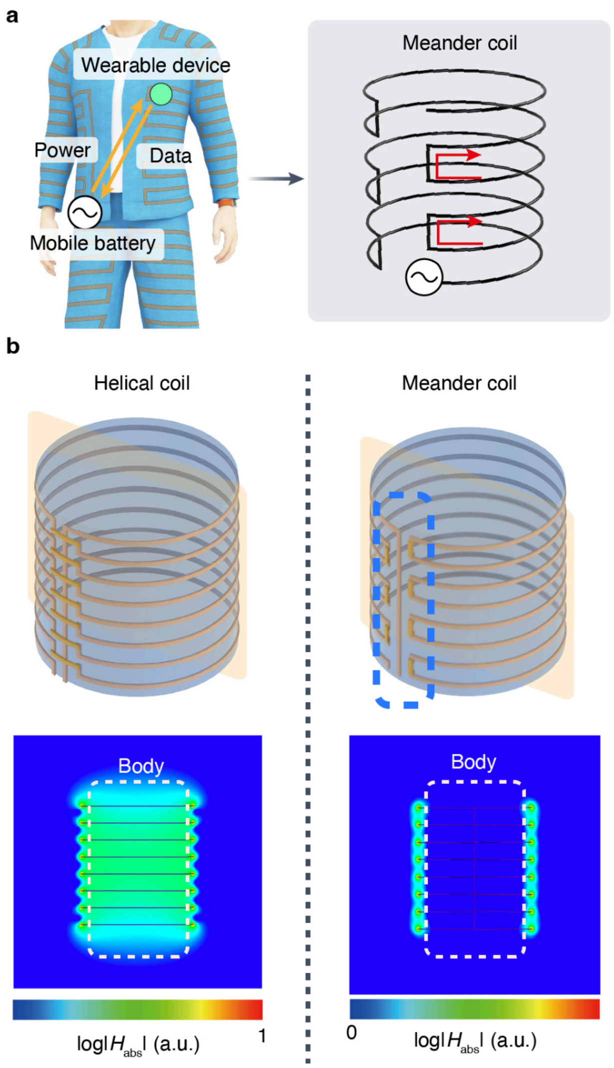

Figure 1: Design of Full-body WPT. (a) Schematic of meander coil. (b) Electromagnetic simulation of meander coil compared to standard helical coil.

The spacing and width of the traces were optimized to maximize magnetic field strength while minimizing resistive loss. The resonant frequency of the meander coil is tuned at 13.56 MHz.An important feature of this design is its scalability. Multiple meander coils can be distributed over the entire body, forming a continuous or semi-continuous power path that adapts to the user's posture. Because the magnetic field remains close to the surface, this configuration allows power to be routed across the torso, limbs, and joints without significant interference or loss. The flat and flexible nature of the coil makes it compatible with integration into textiles, enabling seamless wireless power delivery in wearable garments.

Figure 1 b shows simulation results for the inductive field generated by two coil types—a body-scale helical coil, and a meander coil, —analyzed using the electromagnetic solver Altair Feko. The results indicate that the meander coil effectively confines the magnetic field near the skin surface, in contrast to the helical coil, which generates a more dispersed field that extends deeper into the body. Therefore, The meander coil further enhances this surface confinement, suggesting a design path for even more localized and efficient on-body power delivery.

4 System design

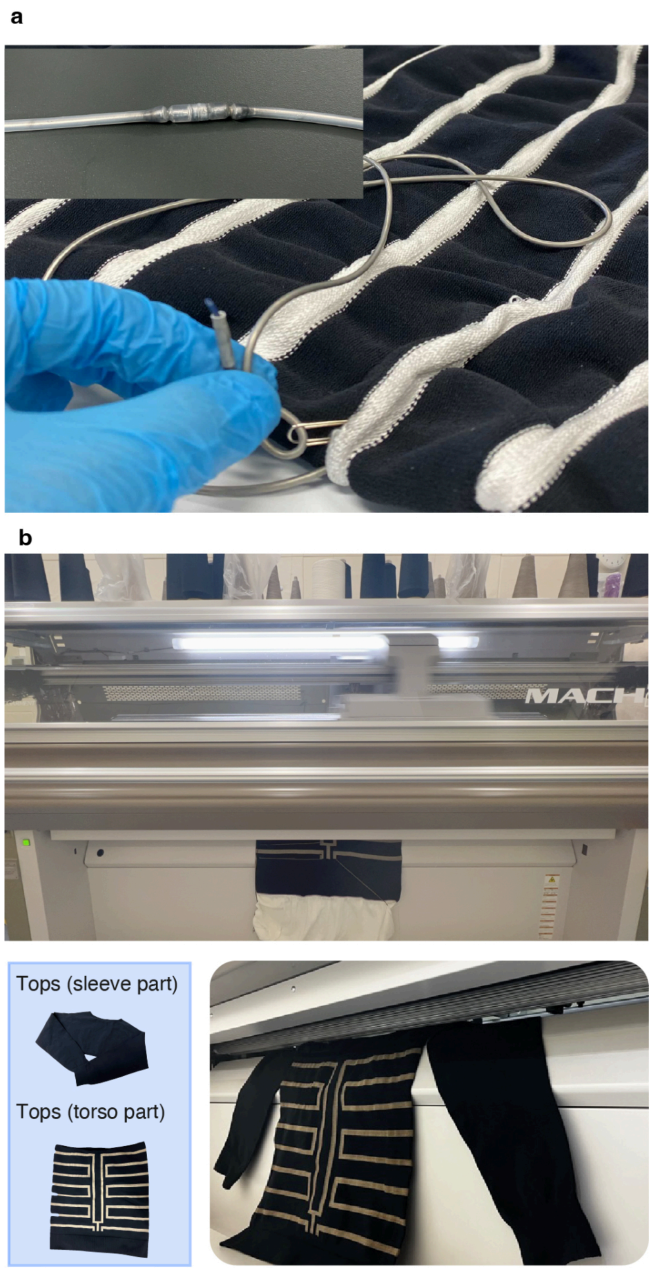

Figure 2: Fabrication of textile meander coil using (a) manual inserting of liquid metal tube or (b) machine knitting of conductive yarn.

The meander coil architecture proposed in this work is highly compatible with diverse fabrication techniques. Its zigzag pattern, characterized by repeated directional reversals, is geometrically simple and well-suited for scalable manufacturing. One approach is to form the coil using liquid metal injected into soft tubing (see Figure 2 a). This method enables flexible and stretchable layouts, allowing coils to conform to the shape of the body. Although the overall system weight increases due to the volume and density of the tubing, this approach remains viable for applications where stretchability is critical.

More importantly, the regular and repetitive structure of the meander coil makes it particularly suitable for machine knitting using conductive yarns (see Figure 2 b). Industrial knitting machines can produce long, uniform coil patterns directly into textile structures, enabling seamless integration with garments. This method offers high design flexibility, supports mass production, and maintains the softness and wearability required for everyday use.By leveraging these established textile fabrication methods, the meander coil design can be realized at scale, supporting the deployment of full-body wireless power networks in practical settings. However, the high resistance of the conductive yarns results in the energy loss of wireless powering even when we use the meander coil structure. This study implements two types of the meander coils using either liquid metal or conductive yarn, and compares their wireless powering performance against user's motion, i.e., coil deformation.

5 Power transfer efficiency

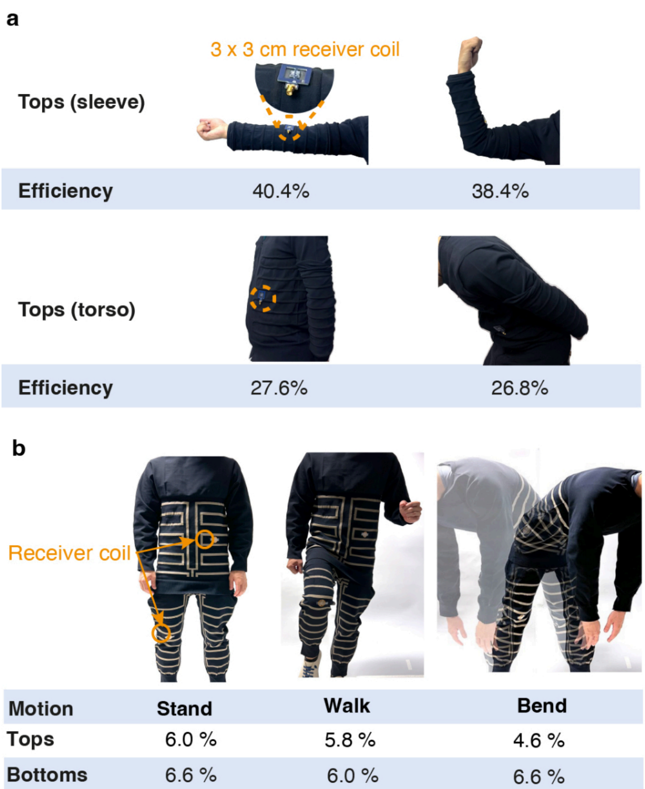

Figure 3: Wireless power performance of (a) liquid-meta-based textile meander coil and (b) conductive-yarn-based meander coil against its coil deformation.

To evaluate the robustness of the wireless power performance of meandered e-textiles against user's motion, we conducted simple efficiency measurements when the two types of meander coil is deformed. Remarkably, the power transfer efficiency remained almost the same, keeping the relative high efficiency (see Figure 3 a). Such high efficiency allows watt-class power delivery during the motion, enabling the continuous operation of advanced wearable devices such as wearable bioimager *(Yokota et al., 2020)*. While the conductive yarn lowers the power transfer efficiency (see Figure 3), this still enables the mW-class power delivery, allowing the stable operation of the battery-free NFC sensor tags *(Takahashi et al., 2025)*. Therefore, by selecting the appropriate coil material according to the power requirements of the target device, the meander coil can flexibly support a wide range of wearable applications.

6 Application examples

Textiles are ubiquitous in daily life, serving as soft, flexible interfaces between the human body and the environment. Recent advances in stretchable electronics are transforming passive fabrics into electronic textiles (e-textiles) with sensing, actuation, and display capabilities. These developments lay the foundation for the "Internet of Textiles" — large-scale textile networks that collect and share physiological and environmental data to support personal health, behavior change, and smart city infrastructure.

Our wireless power textile platform enables a range of applications in Internet of Textiles. As illustrated in Figure 4, the system supports seamless power delivery to multiple on-body devices through a network of meandered e-textiles integrated into clothing. A small mobile battery can energize the entire network, allowing users to move freely while powering distributed sensors and actuators. In the home environment, the system can support continuous health monitoring, such as temperature, heart rate, or motion tracking, without requiring battery changes. While walking or interacting with devices, wearable sensors can communicate with ambient systems, contributing to smart home integration. During seated activities, such as remote work or gaming, the textile can power haptic feedback actuators in the arms or hands, enabling more immersive interaction. At night, the system can continue to deliver power to sleep monitoring devices, maintaining data collection without disturbing the user.

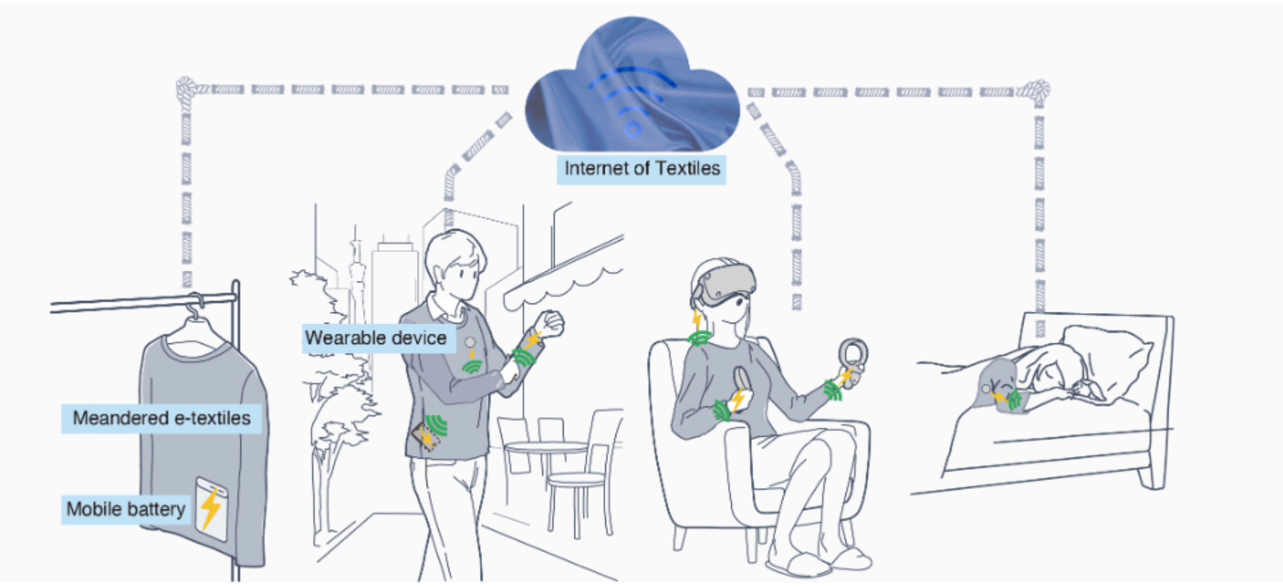

Figure 4: Illustration of Full-body Internet of Textiles using textile-based near-field power and data networks. Our textile-based network enables to wirelessly send power and data to multiple on-body devices around the body.

7 Discussion

Meander coils can be fabricated using a range of conductive materials, each with trade-offs between efficiency, weight, and ease of integration. Liquid metal, for example, offers low resistance and high power transfer efficiency. However, its use requires thick tubing, resulting in substantial added weight—often exceeding 100 grams—which limits its practicality for daily wearable applications. In contrast, conductive yarns can be machine-knitted directly into garments, providing excellent flexibility and low weight. Yet, their higher electrical resistance leads to significant power loss, reducing overall efficiency to around 5%.To address this trade-off, we adopt copper-coated fabric as the conductor for the meander coil. This material combines the benefits of low resistance —achieving efficiency comparable to liquid metal—with lightweight, textile-compatible form factors.

8 Conclusion

We presented a body-scale and energy-efficient wireless power network for the human body, using stretchable meander coils integrated into textiles. By confining the magnetic field near the skin surface, the system enables safe and continuous power delivery across the entire body, even during motion. Our design overcomes key limitations of previous approaches, such as high resistive loss in conductive threads and the excessive weight of liquid metal systems. Electromagnetic simulations confirmed strong surface-localized fields and high power transfer efficiency, while real-world applications demonstrated the potential for powering full-body wearable devices. This work lays the foundation for scalable and comfortable electronic textiles that go beyond sensing to support active functionality. Combined with data connectivity *(Tian et al., 2019, 2023)*, such power networks open new opportunities for the Internet of Textiles—enabling health monitoring, immersive feedback, and responsive environments in everyday life.

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