News and Perspectives

Smart Textiles Tackle Wound Healing, Climate Adaptation, and Reproductive Health

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Abstract

From smart phones to smart fridges to smart... clothes? In this *News and Perspectives* article, JMIR Correspondent Virginia Gewin reports on the evolving smart textile industry and its current and future applications for well-being.

Key Takeaways:

- Smart textiles are moving from sensing to programmable actions.
- Technical advances such as conductive yarns, flexible sensors, and advanced nanomaterials are shaping the next generation of smart textiles.
- Washability, durability, and cost are the biggest challenges.

In 2024, David Armstrong, DPM, PhD, director of the University of Southern California Center to Stream Healthcare in Place (C2SHiP), published a study that teased the future of "smart" wound management materials—for example, dressings equipped with sensors able to detect inflammation or volatile organic compounds that indicate infection.

Two years later, "these materials are very much on the cusp of widespread use," says Armstrong. He points to dressings that change color when they hit a certain pH to identify infections as early as possible. Wounds that are healing well are slightly acidic, but infected or chronic wounds become alkaline, with a pH of 7.0-9.0, due to bacterial activity.

A world leader in diabetic foot care, Armstrong is a self-described early adopter of the technology. Diabetic foot ulcers, open sores on the bottom of the foot or toes due to poor blood flow and nerve damage, affect up to 15% of people with diabetes. Since roughly 85% of diabetes-related amputations are preceded by a foot ulcer, their care and prevention is a key concern.

Wearable health devices are expanding beyond smart watches that monitor pulse, sleep, or blood oxygen. "The next step is to put this technology into clothing," says Armstrong. Researchers are taking that next step—"smart socks," for example, have evolved from monitoring temperature to also measuring pressure and blood oxygen to help identify diabetic ulcer risk early.

Other applications—ranging from sports performance to climate adaptation to fertility tracking—are also driving rapid growth in the smart textiles industry. And as the technology advances, "smart textiles" are rapidly moving from simply sensing skin conditions to taking actions, such as delivering antibiotics or adjusting pressure in response to real-time swelling.

Climate Adaptation

Temperature control—for sports performance, climate adaptation, and even the military—has been a key goal of first-generation smart textiles.

The vast majority of cooling smart textiles on the market currently rely on passive cooling strategies, like evaporative cooling or moisture wicking. In 2023, Chi Yan Tso, PhD, Chair Professor of energy and sustainability at the City University of Hong Kong, published a study demonstrating how a ceramic coating made of metal oxide nanoparticles achieved 99.6% solar reflectivity. His team subsequently applied the same principle to yarns and found that they can reflect 95% of incoming solar heat. When the particles are incorporated into the filament, they form numerous light-scattering interfaces within the material. When light hits the material, these interfaces scatter the radiation, thereby minimizing its absorption, says Tso.

Tso founded a start-up company called i2Cool Limited in 2021 to commercialize the core technology and collaborate with international fashion and sportswear companies. But he says there are other uses as well. "Outdoor workers, if they wear our clothing, can prevent heat shock," he says.

Much of the smart textile research and development is taking place in eastern Asia, where the bulk of the world's textiles are produced. Eastern European researchers, however, have also been developing smart textiles for wartime. "It has military uses, for example, so that soldiers won't be easy to find through thermal cameras," says Sandra Varnaitė-Žuravliova, PhD, a textile researcher at the Center for Physical Sciences and Technology in Kaunas, Lithuania.

Varnaitė-Žuravliova says that phase-change materials—substances that absorb and release body heat to maintain a stable temperature—are a particularly active area of smart

textile research. “The most cooling achieved so far is, at most, 5 degrees Celsius,” she says, of phase change material–based passive cooling garments currently on the market. “Creating climate-resilient clothing is now one of the biggest motivators of the smart textile industry—alongside sports performance and medical uses,” she says.

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Smart Underwear

Women-specific medical research has been woefully overlooked and understudied for decades—but smart underwear aims to help change that.

As a biomedical engineer training at the University of Toronto, Parnian Majd, MEng, initially worked on wearable devices to monitor heart health and sleep quality, but she wanted to create a product that would help women track their own menstrual cycles and fertility windows. As founder and CEO of Fibra, Inc, she has developed a product—officially launching in October 2026—that continuously tracks biomarkers of reproductive health, including vaginal discharge, pH, temperature, heart rate, and other indicators of ovulation, endometriosis, and perimenopause. Majd and colleagues detailed real-world biomedical applications and offered a pathway for future development of wearable thermal monitoring textiles in a 2026 review.

Majd’s team spent two years collecting 500,000 minutes of beta-testing wear-time to improve the comfort and performance of the product. “When it comes to underwear, it’s a very private area. We don’t want solid electronics or wires,” she says. Over the last 5 years, she developed yarn-based sensors, embedded in the underwear, able to collect data around the clock. In a front panel of the underwear, a detachable electronic module encrypts and downloads the data to a phone or computer.

“The next phase will be detecting a pregnancy, sexually transmitted disease, urinary tract infection, or bacterial vaginosis,” says Majd. “Women want insights into their bodies,” she adds. With all of the aggregate data collected, researchers can use large language models and AI to make deeper sense of the data, she explains.

“Washability is the biggest challenge,” Majd says. Other smart textile researchers agree that figuring out how smart clothes can be reused and maintain their functionality has been the key hurdle. Sensitive electronic sensors must survive sweat as well as harsh detergents and submersion in water to get them clean. It took a lot of testing, in various detergents and washing conditions, but Majd’s team identified optimal chemical modifications to the yarn to protect the electronics.

Future Outlook

The future of smart textiles will harness AI. “The integration of AI with functionally integrated knitted textiles transforms soft wearables from passive sensing garments into intelligent, responsive systems that actively support human performance, rehabilitation, and interaction,” according to a 2026 paper by Irmandy Wicaksono, MSc, PhD, an assistant professor and design engineer at the National University of Singapore. “I’m intrigued by moving beyond electronic applications to mechanical or fluidic applications,” says Wicaksono. “What if we can program the yarn so it either shrinks or expands?” he asks. Pants, for example, could sense muscle condition and activity in real time and apply precise compression or stimulation.

Wicaksono says the ability to integrate sensors into various textiles using embroidery, knitting, weaving, and braiding will allow researchers to optimize both electrical and mechanical properties and control exactly how and where a textile alters its shape in response to signals. Computation and communication can also be embedded directly into the fabrics themselves, he explains.

Since personal expression is at the heart of fashion, Wicaksono notes that many smart textile designers keep culture and identity at front of mind. “Programmable multifunctional textiles that can do general physiological sensing and also offer active interventions could also be designed to have a unique appearance,” says Wicaksono. “I think that would be the sweet spot.”

Keywords: smart textiles; wearable electronic devices; sensors; nanomaterials; conductive materials; biomedical technology; health and well-being; clothing

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