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Stretchable knee wearable offers insight into improving e-textiles for health care

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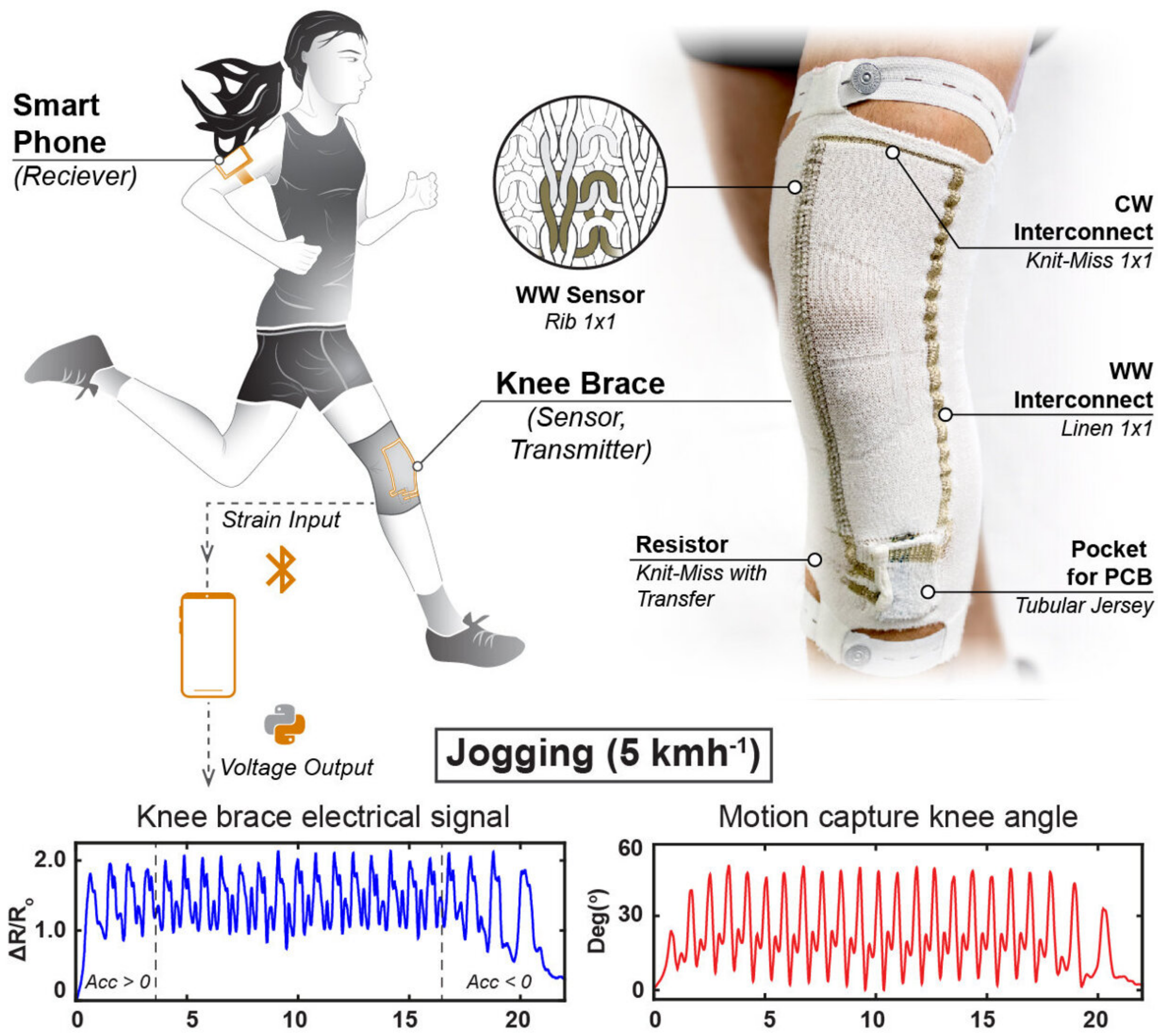

The smart fully knitted knee brace seamlessly integrates multiple flexible electrical components into a stretchable circuit. When worn, the knee brace converts changes in one's knee joint to electrical signals, enabling the wireless and continuous real-time sensing of one's knee joint motion. Credit: SUTD

Mobility limitation is an initial stage of human mobility disability and an early sign of functional decline. It can manifest as muscle weakness, loss of balance, unsteady gait, and joint pain. Long-term and continuous monitoring of joint motion may potentially prevent or delay decline by allowing the early diagnosis, prognosis, and management of mobility-related conditions.

This long-term and continuous monitoring is made possible by analysis systems that are either non-wearable or wearable. Non-wearable systems are reliable, but require a laboratory environment and trained individuals and are therefore impractical for daily use. On the other hand, wearable systems are portable, cheaper, and much easier to use. Unfortunately, typical wearable sensors tend to be inflexible and bulky.

A relatively new player to the wearable systems field are wearables made from conductive fabric (CF), which are soft, lightweight, malleable, and non-invasive. These sensors are comfortable and suitable for long-term monitoring. However, most CF-based wearables become error-prone if displaced from their intended location and rely on external components that restrict the sensitivity and working range of the sensors.

To overcome these limitations, a research team created a wearable with a high degree of functional and design freedom. Associate Professor Low Hong Yee and her colleagues from the Singapore University of Technology and Design (SUTD) collaborated with Dr. Tan Ngiap Chuan of SingHealth Polyclinics and published their research paper, "All knitted and integrated soft wearable of high stretchability and sensitivity for continuous monitoring of human joint motion" in *Advanced*

Healthcare Materials.

According to Associate Professor Low, their key considerations when designing the wearable were sensor data accuracy and reliability and for the sensor to rely on as few external components as possible. The result was a highly stretchable, fully functional sensing circuit made from a single fabric. Because the knee joint is important for lower limb mobility, the wearable was designed for the knee.

To develop this single-fabric circuit, the team mechanically coupled an electrically conductive yarn with a dielectric yarn of high elasticity in various stitch patterns. Dimensions were customized according to the subject's leg. The functional components—sensors, interconnects, and resistors—formed a stretchable circuit on the fully knitted wearable that allowed real-time data to be obtained.

However, putting together sensors, interconnects, and resistors in a single stretchable knit is difficult. Associate Professor Low mentioned that "the synergy of yarns with different electrical and mechanical properties to achieve high signal sensitivity and high stretchability" was challenging, as the desired properties for each component were vastly different.

Sensors need to produce a large change in resistance for enhanced sensitivity, while interconnects and resistors need fixed resistances of the highest and lowest values, respectively. As such, the researchers optimized yarn composition and stitch type for each component before connecting the functional circuit to a circuit board contained in a pocket of the wearable, allowing for wireless transmission of real-time data.

With a soft knee wearable developed, its components functional, and data transmission possible, it was time to test the performance of the wearable. The team assessed the wearable through extension-flexion, walking, jogging, and staircase activities. Subjects wore the knee wearable together with reflective markers that were detected by a motion capture system, allowing the comparison between sensor data and actual joint movement.

The sensor response time was less than 90 milliseconds for a step input, which is fast enough to monitor the human movements included in the study. Additionally, the smallest change in joint angle that the sensors could detect was 0.12 degrees. The sensor data showed strong correlation with joint movement data acquired from the motion capture system, demonstrating reliability of the sensor data.

The potential impact of such device in the medical field is huge. Long-term continuous monitoring of joint motion is important to track mobility-related conditions. Often, people ignore early signs of mobility decline as they are not deemed serious enough to seek help. Wearable technology solves this problem by assessing a user's mobility directly in real-time.

Embedding a user-friendly sensor circuit into a soft and comfortable fabric may increase the public's adoption of wearable technology, especially among athletes and the elderly. Data can be gathered in real-time and translated into indicators that can detect mobility decline. When signs of mobility decline are found, preventive care, prognosis, and management of the health care condition can be given.

Building on this work, the team intends to study the effect of sweat and humidity on sensor signals and to extend the research to include subjects from both healthy and unhealthy populations in the future. "We have started working on extending the wearable to special user groups and to monitor other body joints, such as the shoulder," stated Associate Professor Low. "We're also looking at securing an incubation fund to explore the commercialization potential of the wearable."

More information: Ujjaval Gupta et al, All Knitted and Integrated Soft Wearable of High Stretchability and Sensitivity for Continuous Monitoring of Human Joint Motion, *Advanced Healthcare Materials* (2023). DOI: 10.1002/adhm.202202987

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