A skin sensor that can rapidly recognize hand-based tasks with limited training

A skin-like sensory system, consisting of a substrate-less nanomesh strain sensor and an unsupervised meta-learning framework, enables the rapid recognition of various hand movements with minimal training and can work for any user. The device is able to complete various tasks, including virtual keyboard typing and object recognition.

This is a summary of:
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The problem

Technologies for human–machine interfaces have a key role in the development of human augmentation, prosthetics, robot learning and virtual reality[1]. Devices for tracking hand movements can enable tasks such as object recognition, object manipulation and even communication. Several promising methods using electromyography wrist bands[2] or electronic gloves[3] combined with machine intelligence have been explored to enable the identification of various hand gestures and tasks.

However, there remains a big gap between the capabilities of these technologies and of humans in terms of precision, learning speed and power consumption. Present devices require multiple sensors on the hand to pinpoint movements at each joint, making the system bulky. Moreover, present technologies rely on supervised learning models, which require intensive data collection for each new user and task, preventing them from being widely adopted. Therefore, a simple yet accurate system that incorporates both sensory and algorithmic efficiency is needed.

The solution

The obstacles to rapidly and precisely digitizing human hand motions include the need for complex multisensing arrays to determine fine hand movements and the inefficient use of data by present learning models. Inspired by skin receptors and human intelligence, we designed sensors and an algorithm to translate the stretching of the skin into hand proprioception (that is, an awareness of the location and movements of the hand), with the ability to rapidly learn how to perform unknown tasks following minimal training.

Unlike conventional sensor designs, we printed a substrate-less biocompatible nanomesh directly onto the user's hand. This approach makes it possible to capture unique signal patterns from the stretching of the skin related to hand proprioception. The device then wirelessly transmits the signal for further processing (Fig. 1a). We discovered that the substrate-less nanomesh could capture the movement of individual joints and that the signal can be used to encode multi-joint proprioception. This capability is an advantage when incorporating our device into daily-use electronics because the algorithm learning process is fast for the single compressed signal owing to its low-dimensional properties. We initially used meta-learning to identify the unlabelled signals for random hand gestures using a contrastive learning architecture to discriminate between different signals. We discovered that this prior-learned network could separate unlabelled hand motions including various finger motions and wrist movements. Our learning network provides robust learning of signal patterns from the nanomesh; therefore, it can quickly adapt to various interactive tasks and users following only a few labelling attempts. The following process is used to operate the substrate-less device: first, the user prints the biocompatible nanomesh onto their hand; next, the wireless unit is attached; then, the user provides a few-shot labelled dataset (<5 times) to fine-tune the prior-learned network with few training epochs; finally, the system rapidly learns and adapts to multiple unknown tasks, such as virtual keyboard typing and the recognition of random objects (Fig. 1b).

The implications

Our approach mimics the way that humans use their sensory inputs to learn tasks. Specifically, our approach highlights the synergistic fusion of sensory hardware design and algorithms, where the developed sensor delivers informative signals with low-dimensional properties, which maximizes the performance of our fast-learnable network.

In this work, we printed a single nanomesh network onto the index finger of each hand. This approach enabled the recognition of keyboard typing and object grasping. We anticipate that an increased number of nanomesh elements on multiple fingers will allow a greater range of motions to be captured. However, the number of sensors should be carefully considered, as more sensors will result in a greater amount of data to be analysed.

We are interested in exploring applications of this technology in telemedicine and robotics. Since our nanomesh can be directly printed onto any skin surface making it imperceptible to users, our system can learn dexterous and distinctive movements of clinicians, enabling remote physical therapy and physician training. With more sensors, it would be possible for the network to quickly learn sign language for different users. Moreover, if combined with wearable exoskeletons, the device could provide rich information for closed-loop sensing and actuation, and enhance the capabilities of existing technologies.

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EXPERT OPINION

"This paper is interesting and the results are useful for the further development of next-generation wearable electronics. The article introduces a directly printable on-skin nanomesh sensor without any other substrate. It consists of nanowires with a Au–Ag core–shell structure and polyurethane for reinforcing. The softness and thinness of the sensor enables decoupling of skin movement in different positions. Additionally, the authors demonstrate gesture recognition with multiple participants using a learning model." **Sunghoon Lee, The University of Tokyo, Tokyo, Japan.**

FIGURE

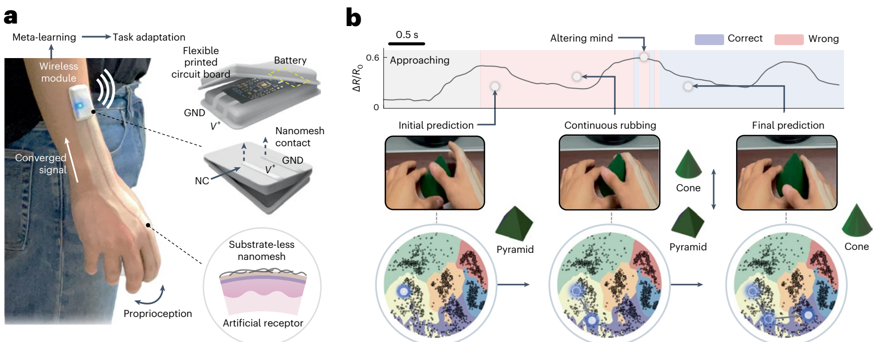

Fig. 1 | A skin sensor combined with a meta-learning framework. a, A biocompatible nanomesh is printed onto the hand to replicate human skin receptors. The wireless module is directly attached to read the signals, and the network is further trained through few-shot meta-learning. The insets show the wireless module and nanomesh. **b**, The device can recognize objects and produce a uniform manifold approximation and projection (UMAP) of embedded vectors for the signals. The colours represent the different shapes with yellow being a pyramid and purple a cone. The UMAP position changes as the user interacts with an object and finally identifies it. The upper plot shows the relative resistance ($\Delta R/R_0$) measured throughout the interaction. NC, nanomesh contact. © 2022, Kim, K. K. et al.

BEHIND THE PAPER

My previous studies on wearable human–machine interfaces explored the promise of machine intelligence for decoding the vast amount of information obtained by soft sensors[4]. Broadening the scope of my studies, I began research with Professor Bao, which led me to uncover important new avenues. I took particular note of how our bodies effectively manage sensory inputs and process information. I was interested in how we could use the aspects of human learning that make it possible to rapidly adapt to tasks with only a handful of trials, known as meta-learning[5], which is widely researched in the machine learning community. From this initial idea, I developed an information-rich skin receptor that seamlessly integrates with the learning network, allowing fast processing. By demonstrating the synergistic potential of the newly developed sensor and algorithm, I hope that this result will open up new possibilities in the field of advanced wearable electronics. **K.K.K.**

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FROM THE EDITOR

"This works shows that a conformal single sensor combined with a meta-learning algorithm can recognize hand motions from resistance changes caused by stretching of the skin. Notably, tasks can be readily adapted to new users using freshly printed sensors." **Katharina Zeissler, Associate Editor, *Nature Electronics*.**