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On-Skin Computing

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MODERN WEARABLE COMPUTERS are miniaturized, offer unprecedented mobility, and can even interface with the human body to monitor vital signs. Yet they have much more in common with their ancestor—the PC—than you might think. Just like old-fashioned computers, they are made of conventional electronics and therefore remain rigid and rather thick. This not only compromises ergonomics, but also limits the size of the devices and restricts where they can be deployed on the user. Can we instead make computers soft and malleable, such that they truly adapt to the human body?

A new generation of wearable devices, redesigned from the ground up, promises a significantly better compatibility with the human body. These so-called *epidermal devices*—devices modeled after human skin—are made of soft and stretchable materials and are two to three orders of magnitude thinner than traditional devices; in fact, they are typically much thinner than the diameter of a single strand of hair.[2] Therefore, they can be worn as a barely noticeable patch on the skin. Embedded functional materials create fully flexible electronic components for sensing, output, processing, and power in a micron-thin form factor (see Figure 1).

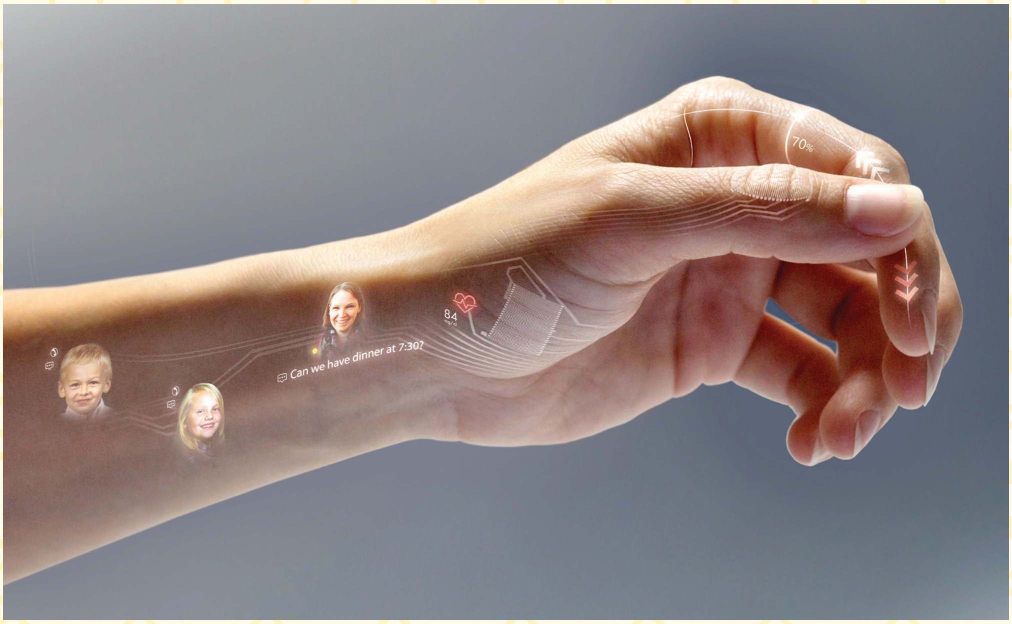

Figure 1. Future on-skin computing devices could seamlessly blend with the human body as visualized in this concept illustration of iSkin.[7]

The unique properties of skin have long fascinated researchers and have inspired electronic skin, soft sensors that mimic skin's mechanical properties while offering human-like sensory capabilities.[1] Initially targeted at robots, electronic skins are increasingly being used on the human body. In recent years, a new multidisciplinary community has formed across the fields of new materials, electronics, biomedical engineering, and computer science that has made significant breakthroughs. This involves not only fundamental issues of materials and manufacturing, such as further improving minimally invasive wearability,[4] but also functional designs for a wide range of applications.[6]

Can we make computers soft and malleable, such that they truly adapt to the human body?

While early work focused primarily on monitoring biosignals, it soon became clear that devices on the skin offer principled new avenues for human-machine interfaces. We are investigating these at Saarland University as part of a five-year research project entitled "Interactive Skin," funded by the European Research Council (ERC). Combining European strengths in human-computer interaction, graphics, AI, and specialized hardware technologies, our goal is to contribute to a new generation of devices that computationally augment the natural functions of our skin.

Merging Human Skin with Computational Augmentations

Controlling computing devices in demanding mobility conditions is a long-standing challenge, such as when the user's hands are busy holding an object or when the situation does not allow them to look at a screen. Devices worn on the skin offer a promising solution: a thin membrane with a touch sensor can be adapted to different parts of the body and provides an easy-to-reach surface for gestural input.[7] For example, on a sensor placed on the index finger, users can make subtle touch gestures with their thumb, even while holding objects. Additional sensors to detect skin deformation and stretchable displays can also be integrated[8] (see Figure 2 for examples).

Ultrathin devices on the skin can also lead to more natural experiences in augmented reality and virtual reality. To augment the use of everyday objects, we have presented a first-of-its-kind device for what we call feel-through haptics.[9] The minimally invasive temporary tattoo is worn on the finger pad. It is so thin and soft that it even conforms to fine wrinkles, allowing users to feel real-world objects or surfaces they touch through the device. At the same time, the device augments real-world cues with high framerate electro-tactile output generated by eight densely spaced electrodes. This enables novel forms of tactile augmented reality. For example, the system can change the way users perceive materials and objects, or it can create virtual haptic elements, such as virtual buttons, that the user can feel on an object even though they are not physically present.

Computational Design for Wearable Devices that Match the Human Body

Fitting devices to the anatomy of the human body unlocks exciting new opportunities, but it also makes the design of those devices more challenging. Not only does the device need to fit comfortably, but sensors may need to be positioned precisely on the body to detect body movement or pick up biosignals. This multifactorial design space makes it difficult even for experts to manually find optimal device designs. We see great potential for computational approaches to replace manual device design. In our recent work, we have shown that computational optimization with anatomical models enables rapid design of highly compact physiological sensing devices that outperform expert-generated designs.[5] The resulting designs can be printed on an office inkjet printer to create functional sensor tattoos.

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First skin devices are already commercially available.[3] However, many issues remain to be addressed before skin computers can enter mainstream. One important aspect relates to understanding social perceptions of using on-skin devices.[10] In addition, the integration of processing, power supply, and networking into ultrathin and stretchable devices remains a formidable challenge that, once solved, could change computing and how it integrates with our body.

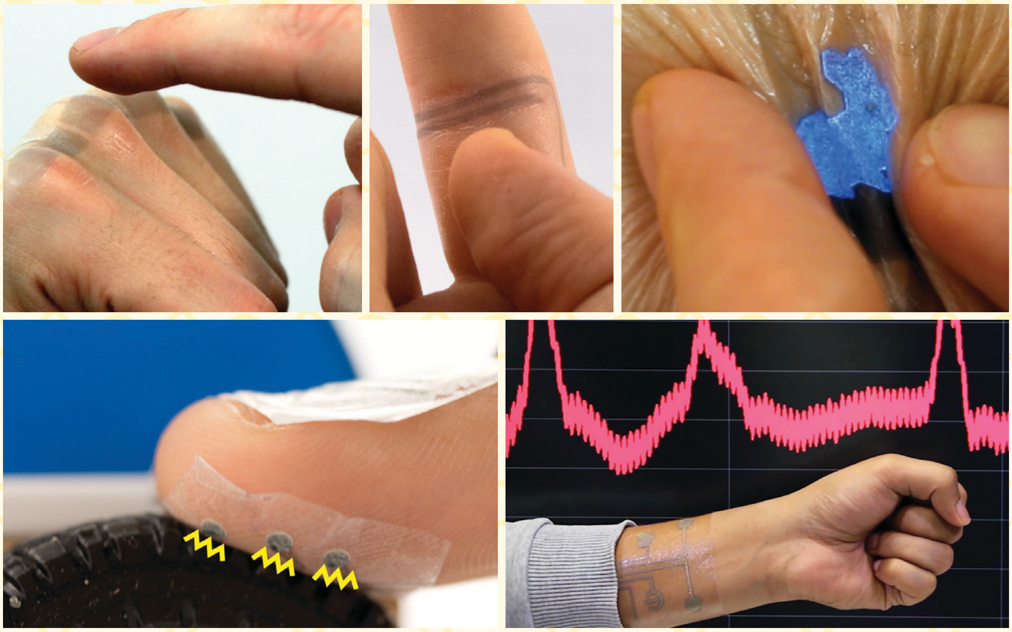

Figure 2. On-skin devices provide various functions, such as user input with rapid touch gestures, visual output, feel-through haptic feedback, and continuous monitoring of body vitals.

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