Design and Fabrication of Body-Based Interfaces (Demo of Saarland HCI Lab)

Jürgen Steimle
Saarland University,
Saarland Informatics Campus
Saarbrücken, Germany
steimle@cs.uni-saarland.de

Marie Muehlhaus
Saarland University,
Saarland Informatics Campus
Saarbrücken, Germany
muehlhaus@cs.uni-saarland.de

Madalina Nicolae
Saarland University
Saarbrücken, Germany and
Léonard de Vinci Pôle Universitaire
Paris La Défense, France
madalina.nicolae@devinci.fr

Aditya Shekhar Nittala
Saarland University
Saarbrücken, Germany and
University of Calgary
Calgary, Canada
anittala@ucalgary.ca

Narjes Pourjafarian
Saarland University,
Saarland Informatics Campus
Saarbrücken, Germany
pourjafarian@cs.uni-saarland.de

Adwait Sharma
Saarland University
Saarbrücken, Germany and
University of Bath
Bath, United Kingdom
sharma@cs.uni-saarland.de

Marc Teyssier
Saarland University
Saarbrücken, Germany and
Léonard de Vinci Pôle Universitaire
Paris La Défense, France
marc.teyssier@devinci.fr

Marion Koelle
Saarland University
Saarbrücken, Germany and
OFFIS
Oldenburg, Germany
marion.koelle@offis.de

Bruno Fruchard
Saarland University
Saarbrücken, Germany and
Univ. Lille, Inria, CNRS, Centrale Lille,
UMR 9189 CRIStAL
Lille, France
bruno.fruchard@inria.fr

Paul Strohmeier
Saarland University and
Max Planck Institute for Informatics
Saarbrücken, Germany
paul.strohmeier@gmail.com

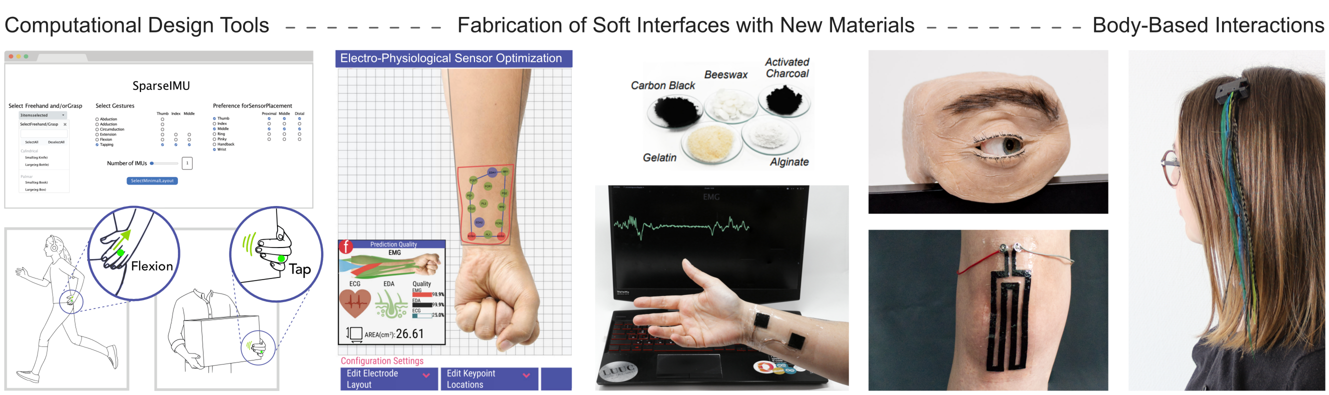

Figure 1: We present five interactive exhibits centered around three themes of critical importance for body-based interfaces: supporting designers with computational design tools, fabrication with new materials, and new avenues for interaction.

ABSTRACT

This Interactivity shows live demonstrations of our lab's most recent work on body-based interfaces. The soft, curved and deformable surface of the human body presents unique opportunities and challenges for interfaces. New form factors, materials and interaction techniques are required that move past the conventional rigid, planar and rectangular devices and the corresponding interaction styles. We highlight three themes of challenges for soft body-based interfaces: 1) How to design interfaces that are optimized for the body? We demonstrate how interactive computational design tools can help novices and experts to create better device designs. 2) Once they are designed, how to physically prototype and fabricate soft interfaces? We show accessible DIY fabrication methods for soft devices made of functional materials that make use of biomaterials. 3) How to leverage the richness of interacting on the body? We demonstrate on-body and off-body interactions that leverage the soft properties of the interface.

CCS CONCEPTS

• **Human-centered computing → Interaction devices**; **Interactive systems and tools**.

KEYWORDS

On-body interaction, computational design, fabrication, new materials, critical design.

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1 INTRODUCTION

The human body surface has unique properties: it is soft, curved, and even stretchable. It continuously deforms and reconfigures when we perform diverse real-world tasks and activities. Moreover, the body is an interface highly unique for every person. These properties largely contrast with our conventional computing devices that are rigid, rectangular, planar, and designed to be one-size-fits-all.

Can we design and build computer interfaces to be soft and malleable, such that they truly adapt to the human body?

At the HCI Lab at Saarland University, we explore the opportunities and challenges of this exciting new field that bridges between interaction design, fabrication, new materials, and computational modeling. We are a diverse, international, and multi-disciplinary team, comprising of computer scientists, roboticists, experts in haptics, textiles, and new materials.

In an ERC project on Interactive Skin, funded by the European Research Council, we have investigated so-called epidermal devices, devices modeled after human skin [5, 7]. They 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 hair. Therefore, they can be worn as a barely noticeable patch on the skin. Embedded functional materials create fully flexible electronic components for sensing and output in a micron-thin form factor. Beyond epidermal devices, other materials and form factors are highly relevant for soft body-based interfaces, too. For instance, electronic textiles and functional body accessories hold great promise, and we investigate them in our lab.

Soft devices offer exciting opportunities for a more natural, more direct, more mobile and more expressive interaction on the body. For instance, we have presented devices for touch input on-the-go that leverage natural tactile guides offered by body landmarks, temporary tattoos for ergonomic sensing of biosignals, and approaches for subtle finger microgestures that are compatible with demanding real-world activities. Ultrathin devices on the skin can also lead to more natural experiences in AR and VR. We have investigated skin-worn visual and haptic displays, and presented a first-of-its-kind device for what we call feel-through haptics. When modeled after the human body, soft interfaces can also open up new avenues for new off-body devices, for instance for human-robot interaction.

In this Interactivity, we present some of our lab's recent research on soft interfaces, structured into three themes (as shown in Figure 1). Each theme represents a fundamental challenge for soft body-based interfaces: design – fabrication – interaction.

2 COMPUTATIONAL DESIGN TOOLS FOR BODY-BASED INTERFACES

Fitting devices to the anatomy of the human body opens up exciting new opportunities, but it also makes the design of those devices more challenging. Not only does the device need to fit comfortably on an individual user's body, but sensors may need to be positioned precisely on the body to detect movement or pick up biosignals, and technical aspects relating to electronics and new materials need to be considered. This multifactorial design space makes it difficult even for experts to manually design optimal device designs. For instance, even with domain expertise in body anatomy and electrical engineering, it is hard to find a good trade-off between high-quality signal acquisition and an ergonomic form factor. We see great potential for computational approaches to replace manual device design. These propose interactive graphical design tools, with model-based optimization and machine learning under the hood. The designer easily and quickly specifies the desired functionality of the interface at a high level. Then, an optimized sensor configuration is computationally generated. In this interactivity, we will show live demos of two computational design tools for skin-based sensors of biosignals [4] and for sensing hand microgestures [6].

Our first demo addresses measurement of bio-signals through electrodes placed on the skin. The captured bio-signals can be utilized in diverse contexts such as gesture recognition, to identify

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the person's physical or mental state, or to increase immersion in extended reality. Prototyping kits have made it easier to create and deploy custom physiological sensing systems. However, designing sensor layouts for acquisition of high-quality signals remains a hard problem, which currently limits a more widespread deployment of this technology. The exact placement of the sensing electrodes on the user's body is critically important for acquiring high-quality signals, as the quality of these signals often changes drastically even with small variations in the placement. The current state-of-the-art is designing an electrode layout manually, using time-consuming trial-and-error by following a set of heuristic guidelines, which is error-prone even for experts.

In this interactivity, we demonstrate a **computational design approach for optimized electro-physiological sensors** [4]. It automates the design of electrode layouts for epidermal electrophysiological sensors to find optimal trade-offs between a high signal quality and ergonomic wearability (compact form factor, fitting to a desired body location). The interactive graphical design tool supports three modalities: electromyography (EMG), electrodermal activity (EDA) and electrocardiogram (ECG). In this demo, we will present our interactive software design tool. Attendees can try out our tool and design customized electro-physiological sensing layouts that fit their body dimensions.

Our second demo showcases a graphical tool for the computational design of body-based sensors for microgestures. In everyday life, people's hands can be free but are often times busy with objects they hold, carry, or use. Recognizing microgestures that are compatible with such context poses a significant challenge due to the demanding spatial configurations and the occlusions that are generated by the object, hands and fingers. **SparseIMU** [6] assists designers in finding optimized configurations of IMUs (Inertial Measurement Units) for sensing finger microgestures. We will demonstrate our design tool to support hand gesture recognition with optimized sensor placement in custom scenarios. The audience will specify requirements, such as their choice of objects, gestures, finger choice, sensor placement constraints, and desired number of IMUs. Utilizing this input, the tool will output optimized sensor placement locations and estimated recognition performance; participants can also alter their choices to evaluate the change in performance.

3 FABRICATION OF SOFT INTERFACES WITH NEW MATERIALS

Realizing soft devices that are compatible with the body requires us to work with materials that are very different from conventional rigid electronics. For instance, commonly used materials include temporary tattoo film or silicone, textiles and leather. Their deformable and stretchable properties demand for novel fabrication tools and new processing methods. Making them electronically functional yet entails an entire different set of challenges. Advances in new materials have presented approaches for conductive, light-emitting or shape-changing soft materials; however these often require expert knowledge and high-end specialized labs and tooling that is not available to the HCI community. In our work, we contribute fabrication methods for new materials that are accessible to a wider group of people, in a DIY setting. These allow HCI researchers, interaction designers, makers and interested hobbyist to create functional prototypes of soft wearable devices, for instance with a simple commodity inkjet printer [1].

Prototyping with soft materials, including the fabrication of novel soft interface types, is a central component of research in body-based interaction. Yet, common prototyping materials are often neither sustainable nor bio-degradable. Recently, DIY formulations for self-produced, sustainable materials, often subsumed under the term "bioplastics", have gained popularity with the maker community. Beyond their promise of sustainability, bioplastics are compelling because they can be tuned to create unique properties including transparency, flexibility, malleability and skin-compatibility, offering inherent benefits for fabricating body-based interfaces. While there has been a range of techniques available for creating *non-conductive* bioplastics using easy-to-obtain materials (e.g., gelatin, agar) and household equipment (e.g., pots and pans), creating bioplastics with *functional properties* (e.g., conductivity) has so-far mostly been the preserve of materials scientists. This is a significant limitation, because functional properties that are vital for creating bioplastic circuits and sensors – i.e., for creating novel interactive devices.

We demo our work on **Interactive Bioplastics** [2]. It presents a DIY approach that enables designers and makers to easily produce interactive elements, for example sensors and circuits, by making use of three types of conductive bioplastic materials: sheets, pastes and foams. In combination, these materials enable a variety of fabrication techniques and application cases. Conductive bioplastic sheets can be patterned (e.g., using a vinyl cutter) to create circuits or bend sensors, pastes allow to stencil-paint skin-exposed EMG electrodes, and the piezoresisitivity of conductive bioplastic foam can be leveraged to create pressure sensors. Our demo showcases these application cases along with a library of material samples. Displaying a variety of functional and non-functional bioplastics provides attendees with an opportunity to hands-on explore the effect of different material formulations.

4 INTERACTION WITH BODY-BASED INTERFACES

Novel materials and fabrication techniques have opened up new, creative ways interfacing the human body surface with technology, including interactions on skin, nails, and hair. Human hair opens up new opportunities for embodied interactions that build on its unique physical affordances and location on the body — it is malleable, extremely versatile, and affords being embedded in natural gestures in very unique ways: hair can be twirled around a finger, curled, knotted or braided. This reveals a design space for gestures that exceed those of planar touch screens, and that allows users to intuitively and unobtrusively provide input. Simultaneously, hair, being public, also enables also the design of interactions that encourage collaboration and interpersonal touch. Yet, these opportunities are so-far little explored.

We present **FeatherHair**, a gesture-controlled hair interface [3]. It realizes robust gesture detection on sensorized hair using a hybrid sensing approach that combines capacitive and piezoresistive touch sensing. The prototype consists of several strands of commercially available (rooster) feather hair extensions. We functionalized these feathers to obtain conductive properties using polymerization – a chemical process that incites conductive polymers to form around individual fibres, in our case a feather's barbs and barbules. It allows the feather to retain its malleability and to softly blend in with natural hair. FeatherHair's software component implements real-time gesture recognition using a random forest classifier trained on a data set comprising five gestures. In our demo, we showcase the fabrication of and interaction with FeatherHair. Hereby, we provide seven samples of feathers that show the effect of polymerisation: Attendees can observe how the feathers progressively blackened with each iteration of polymerisation and become more conductive. Furthermore, our demo also contains six feather samples prepared to be investigated under a microscope. This helps to better understand how the polymers that formed around the feathers' barbs and barbules changed the feather's microscopic surface structure. Providing a functional FeatherHair prototype, we give the attendees the opportunity to gather first-hand experience in the interaction with a hair interface.

Moreover, the human body and the novel properties of soft interactive materials can not only enhance interaction on the body, but also lead to new experiences for interacting with off-body devices. We demonstrate this using using the example of **Eyecam**, an anthropomorphic webcam that looks like a human eye [8]. The purpose of this uncanny interactive device is to invite rethinking our relationship with sensing technology by exploring the implications of their presence on our behavior. Modeled after human anatomy, it is composed of three main parts: the skin layer, the robotic musculoskeletal system, and the eyeball. The device is able to replicate realistic human-like movement and sight through the use of six servo-motors, a small camera, and computer vision algorithms. In our demo, we present the working prototype of Eyecam. The observers will interact with the webcam moving around or looking around. Through embedding a human-like appearance, this webcam highlights the potential risks of hiding the functions of sensing devices and and encourages critical reflection on their impact on human-human and human-device relationships.

5 CONCLUSION

This lab demo highlights key scientific challenges for soft body-based interfaces and illustrates them with recent work from the HCI Lab at Saarland University. Five in-depth demonstrations will be displayed at five stations that attendees can freely approach to actively engage with the projects or passively view. Collectively, these stations showcase some of our recent work within three themes: Computational design tools, fabricating soft devices with new materials, and interacting with the soft body. Attendees will be given (1) the opportunity to try out two computational design tools which enables them to see how our approaches ease design, optimization, and placement of sensors on the body, (2) explore physical samples of biomaterials and other functionalized, soft materials by touching them, and (3) interacting with functional physical prototypes to gather hands-on experience. We further provide posters and additional displays showing, e.g., interactions and application examples for the passive audience to enjoy.

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