BodyHub: A Reconfigurable Wearable System for Clothing

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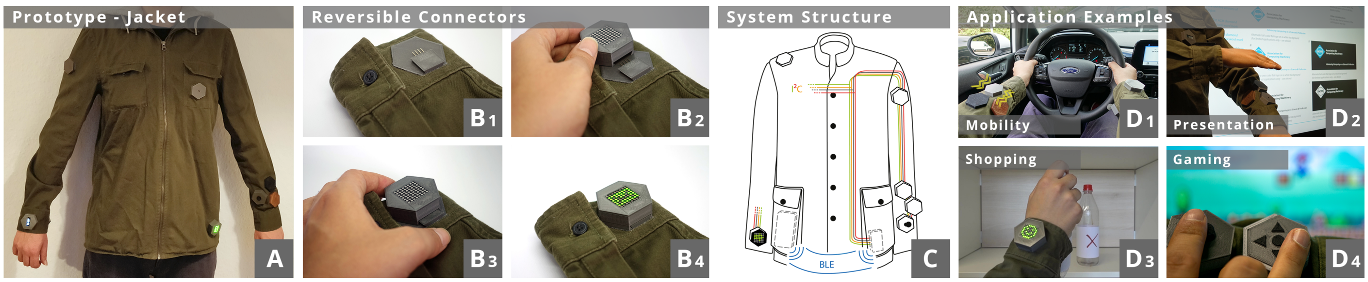

Figure 1. BodyHub (A) is a reconfigurable wearable concept that allows users to extend their garments with rich digital functions (D) by attaching different input and output modules (B) to a garment-integrated bus system (C).

ABSTRACT
While mobile technologies are moving closer to our body and novel wearable gadgets and smart textile interfaces emerge, current approaches are often expensive individual solutions for specific applications and lack reconfiguration possibilities. With this work, we introduce BodyHub, a modular wearable approach that allows users to realize their own smart garment applications by arranging and configuring exchangeable functional modules. To address individual user requirements and preferences, we developed a comprehensive repertoire of input and output modules that can be placed freely onto slide-in sockets which are imprinted in the textile by using 3D printing. Further, we developed a smartphone companion app that facilitates the creation of user-defined system functions without any programming skills. BodyHub thereby allows the creation of personalized wearable solutions by the users themselves and also supports ad-hoc assemblies for interface design explorations in research labs. To demonstrate the range of possible applications, we describe real-world use-cases from the areas of work life, shopping, mobility, and gaming.

Author Keywords
Wearable; E-Textiles; Smart Fabric; Rapid Prototyping; 3D Printing; Wearable Construction Kits; Modular System

CCS Concepts
•**Human-centered computing** → **Interaction devices;** *Mobile computing;* •**Hardware** → **Sensor devices and platforms;** *Reconfigurable logic applications;*

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INTRODUCTION AND RELATED WORK
Mobile technology has woven into our everyday life and provides a powerful digital repertoire of ubiquitous services and smart functions. However, this development also poses problems, as mobile devices often require the full attention of the user and distract from current activities. Wearable approaches, such as Project Jacquardt [10], offer a promising potential to support users in a more unobtrusive way. Prior work investigated wearable construction kits that aim to teach basic electronics and programming skills. They simplify the prototyping of interactive clothing by providing electronic kits and visual programming editors. Projects like EduWear [5], i*CATch [8], or MakerWear [6] empower children to create their own interactive clothings. Interactex [3] provides an environment that is designed for smart textiles and facilitates planning and implementation of wearables with a specific use-case. To support reconfigurability, reversible connectors are still a challenge. Researchers addressed this challenge by using conductive zippers and hook-and-loop fasteners, snap buttons, magnetic connectors, and individual plug connectors (cf. [7]).

In contrast to such prior work, we want to explore a broader scope of scenarios and empower users by allowing them to realize and adapt their own wearable interfaces without effort or the need of technical knowledge. Therefore, we present BodyHub[1] (Figure 1, A), a reconfigurable wearable system for clothing, which allows to combine various I/O-modules to create individual wearables. To provide easily exchangeable modules, we propose a connector system which is directly 3D printed into garments and interconnects the modules with integrated conductors. The communication between the modules is realized with a central unit, which also provides a wireless connection to the user's smartphone. To combine the interaction possibilities of the user-selected modules, we developed an easy-to-use companion app which allows to define customized system functionalities on the go.

[1] For further technical details see: https://imld.de/bodyhub/

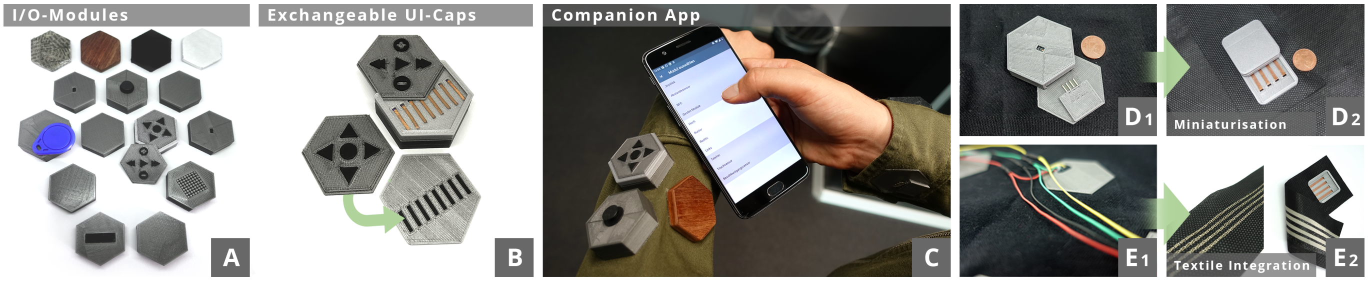

Figure 2. Our prototype comprises 15 modules (A) ranging from displays to customizable touch modules (B). This variety allows the combination of input and output modules to define custom functions with the smartphone app (C). We work on miniaturisation (D1-2) and improved integration (E1-2).

BODYHUB APPROACH AND PROTOTYPE

The BodyHub system consists of four main components: *I/O-modules*, a *socket system* integrated into clothing, a *central control unit*, and a *companion app*.

I/O-Modules and Socket System: At the current stage, we developed eleven different input- and output-modules as well as four decorative modules (Figure 2, A). The functional modules in combination with the easy-to-use 3D-printed sliding mechanism (Figure 1, B) allow to quickly combine various functionalities into one wearable user interface. Since all electronic components are removable, the garment itself only contains passive components, which both improves washability and allows the system to be used over a long period of time even after the garment has worn out. In contrast to previous work, which examined 3D printing on textiles (cf. [2, 12, 9, 11]), we use imprinting to attach the sockets to the garment, which leads to an even stronger bond between the 3D printed object and the fabric. For communication, all sockets are interconnected with wires (Figure 2, E1), which will be textile integrated in our ongoing development (Figure 2, E2).

System Structure and Communication: A microcontroller manages the data communication to the attached modules and is connected to a smartphone via Bluetooth Low Energy (Figure 1, C). Within the companion app, the current input status is validated and the required output is triggered and forwarded to the corresponding component. This component can be the smartphone, a module on the clothing, or a remote-controlled system such as a PC, smart-home device, or AR-glasses. In addition to interaction within the system, this allows to communicate with other devices or prototypes and thus to explore new interaction possibilities in research labs.

Companion App: To accomplish a simple specification of user-defined functions without programming, we developed an Android app according to the If This Then That principle (IFTTT) [4]. To create a BodyHub function, the user simply selects one or more triggers and maps the action(s) that should be executed if these triggers are activated (Figure 2, C).

APPLICATION EXAMPLES

Next, we will briefly go through four promising use-cases.

► **Mobility:** Mobile devices often require high user attention (cf. [1]). For instance, when driving, mobile notifications or navigation instructions can visually distract and endanger the driver. Therefore, an NFC-module can detect when the steering wheel is touched by a corresponding tag and will manage distracting notifications. BodyHub further makes it possible to shift the navigational instructions from the visual to the tactile sense by forwarding the navigation commands to vibration modules (Figure 1, D1).

► **Work:** NFC-Tags can also be used in the work context to automatically log-in when the employee arrives at the workplace or to exchange virtual business cards by handshake with other BodyHub users. Furthermore, the system can act as a remote control which can, for example, be used to handle slide presentations via simple gestures provided by the included gesture module (Figure 1, D2) or via body movements recognized by an orientation module.

► **Grocery Store:** BodyHub can show shopping lists directly on the clothing with an attached display module. The NFC-module also provides object recognition by simply picking up tagged products. This allows the list to be updated and, if necessary, output visual (e.g., on an LED-Display) or tactile (e.g., via vibration module) warnings if a product contains allergens without the need of reading the ingredient list (Figure 1, D3).

► **Gaming:** The capacitive touch module allows to create customized game controllers (Figure 1, D4) without even changing electronics, since the user only has to change the UI-cap that is fully 3D-printed and combines conductive and non-conductive materials in a single print (Figure 2, B).

CONCLUSION AND FUTURE WORK

We presented BodyHub, a modular wearable system for customized body-worn interactions. The combination of several functional modules and the easy-to-use smartphone application allows a reconfiguration adapted to the users' needs even at runtime. To illustrate the versatility, we developed a prototype that implements this concept and enables the user to realize a number of application examples, including context-aware, tangible, and remote interaction. We proposed 3D printing as a suitable approach for garment-integrated sockets and the realization of reconfigurable wearable systems. For future work, we plan to miniaturize the modules (cf. Figure 2, D1-2). We already started to improve the textile integration of the wire conductors (Figure 2, E) and plan to extend the IFTTT principle to allow defining more complex functions, without affecting the ease of use. In addition, we want to explore further applications and evaluate them in field studies.

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REFERENCES

[1] Andreas Bulling. 2016. Pervasive Attentive User Interfaces. *Computer* 49, 1 (Jan 2016), 94–98. DOI: http://dx.doi.org/10.1109/MC.2016.32

[2] Nils Grimmelsmann, Mirja Kreuziger, Michael Korger, Hubert Meissner, and Andrea Ehrmann. 2018. Adhesion of 3D printed material on textile substrates. *Rapid Prototyping Journal* 24, 1 (2018), 166–170. DOI: http://dx.doi.org/10.1108/RPJ-05-2016-0086

[3] Juan Haladjian, Katharina Bredies, and Bernd Brügge. 2016. Interactex: An Integrated Development Environment for Smart Textiles. In *Proceedings of the 2016 ACM International Symposium on Wearable Computers (ISWC '16)*. ACM, New York, NY, USA, 8–15. DOI:http://dx.doi.org/10.1145/2971763.2971776

[4] IFTTT Inc. 2016. If This Then That. (2016). https://ifttt.com/

[5] Eva-Sophie Katterfeldt, Nadine Dittert, and Heidi Schelhowe. 2009. EduWear: Smart Textiles As Ways of Relating Computing Technology to Everyday Life. In *Proceedings of the 8th International Conference on Interaction Design and Children (IDC '09)*. ACM, New York, NY, USA, 9–17. DOI: http://dx.doi.org/10.1145/1551788.1551791

[6] Majeed Kazemitabaar, Jason McPeak, Alexander Jiao, Liang He, Thomas Outing, and Jon E. Froehlich. 2017. MakerWear: A Tangible Approach to Interactive Wearable Creation for Children. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems (CHI '17)*. ACM, New York, NY, USA, 133–145. DOI: http://dx.doi.org/10.1145/3025453.3025887

[7] Andreas Mehmann, Matija Varga, and Gerhard Tröster. 2017. *Reversible Contacting for Smart Textiles*. Springer International Publishing, Cham, 185–198. DOI: http://dx.doi.org/10.1007/978-3-319-50124-6_9

[8] Grace Ngai, Stephen C.F. Chan, Hong Va Leong, and Vincent T.Y. Ng. 2013. Designing I*CATch: A Multipurpose, Education-friendly Construction Kit for Physical and Wearable Computing. *Trans. Comput. Educ.* 13, 2, Article 7 (July 2013), 30 pages. DOI: http://dx.doi.org/10.1145/2483710.2483712

[9] Eujin Pei, Jinsong Shen, and Jennifer Watling. 2015. Direct 3D printing of polymers onto textiles: experimental studies and applications. *Rapid Prototyping Journal* 21, 5 (2015), 556–571. DOI: http://dx.doi.org/10.1108/RPJ-09-2014-0126

[10] Ivan Poupyrev, Nan-Wei Gong, Shiho Fukuhara, Mustafa Emre Karagozler, Carsten Schwesig, and Karen E. Robinson. 2016. Project Jacquard: Interactive Digital Textiles at Scale. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI '16)*. ACM, New York, NY, USA, 4216–4227. DOI:http://dx.doi.org/10.1145/2858036.2858176

[11] Michael L. Rivera, Melissa Moukperian, Daniel Ashbrook, Jennifer Mankoff, and Scott E. Hudson. 2017. Stretching the Bounds of 3D Printing with Embedded Textiles. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems (CHI '17)*. ACM, New York, NY, USA, 497–508. DOI: http://dx.doi.org/10.1145/3025453.3025460

[12] Razieh Hashemi Sanatgar, Christine Campagne, and Vincent Nierstrasz. 2017. Investigation of the adhesion properties of direct 3D printing of polymers and nanocomposites on textiles: Effect of FDM printing process parameters. *Applied Surface Science* 403 (2017), 551 – 563. DOI: http://dx.doi.org/10.1016/j.apsusc.2017.01.112