ARCord: Visually Augmented Interactive Cords for Mobile Interaction

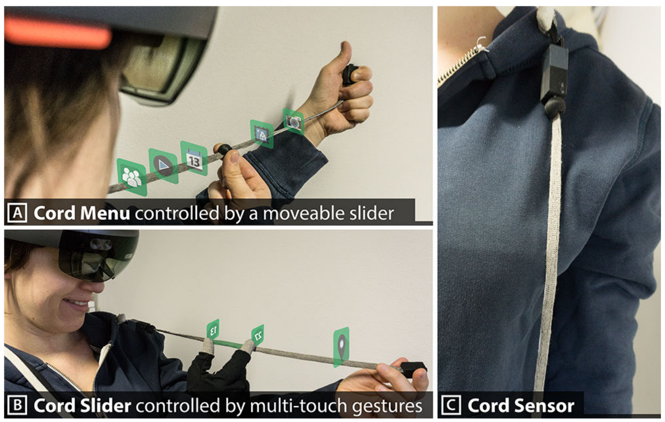

Figure 1: Our visually augmented interactive cords enable unobtrusive and direct interaction capabilities by providing an united input and output space. Our ARCord approach provides mobile menus that can be seamlessly controlled by a moveable cord slider **(A)** or touch input **(B)** on a fully garment-integrated cord sensor **(C)**. All visual overlays are oriented and aligned to the view of the user by using 3D transformations and billboarding.

Konstantin Klamka
Interactive Media Lab
Technische Universtät Dresden
Dresden, Germany
klamka@acm.org

Raimund Dachselt
Interactive Media Lab
Technische Universtät Dresden
Dresden, Germany
dachselt@acm.org

CHI'18 Extended Abstracts, April 21–26, 2018,Montreal, QC, Canada
ACM 978-1-4503-5621-3/18/04.
https://doi.org/10.1145/3170427.3188456

Abstract
Research on wearable controllers has shown that body-worn cords have many interesting physical affordances that make them powerful as a novel input device to control mobile applications in an unobtrusive manner. With this paper, we want to extend the interaction and application repertoire of body-worn cords by contributing the concept of visually augmented interactive cords using state-of-the-art augmented reality (AR) glasses. This novel combination of simultaneous input and output on a cord has the potential to create rich AR user interfaces that seamlessly support direct interaction and reduce cognitive burden by providing visual and tactile feedback. As a main contribution, we present a set of cord-based interaction techniques for browsing menus, selecting items, adjusting continuous values & ranges and solving advanced tasks in AR. In addition, we present our current implementation including different touch-enabled cords, its data transmission and AR visualization. Finally, we conclude with future challenges.

Author Keywords
mobile interaction; cord input; augmented cord; system control; cord-based interaction; wearable; augmented reality.

ACM Classification Keywords
H.5.2 [Information interfaces and presentation]:
User Interfaces: Input Devices and Strategies, Prototyping, Interaction Styles;

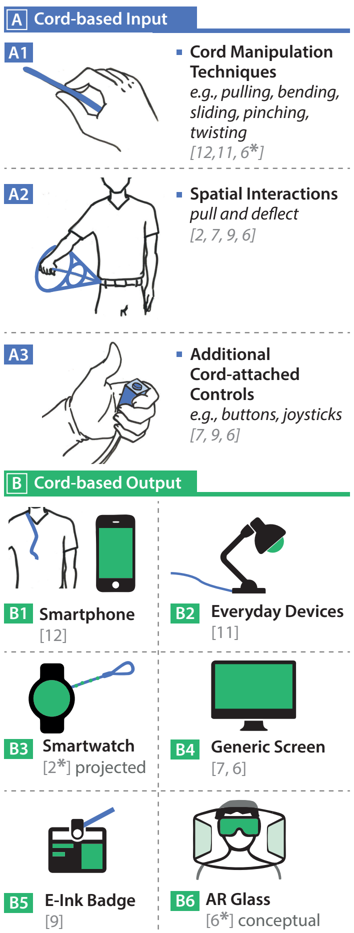

Figure 2: Cord-based I/O: Interactive cords have been investigated with respect to their ***input capabilities* (A1-A3)** and have been combined with different ***output devices* (B1-B6)**. The asterisks show conceptual or not completely implemented work.

Introduction

The future of mobile computing is characterized by a rapid technological development and an ongoing miniaturization of body-worn devices including smartwatches, interactive jewelry & accessories [14], and high-quality augmented reality (AR) glasses that allow users to access information at any time. This trend is accompanied by emerging garment-integrated sensor networks that will enable subtle and unobtrusive mobile interactions having the potential to become rich, body-related digital hubs in the near future. Already today, E-Textiles extensions, e.g., for jackets [10], body-worn cords [12], sleeves [8] or trousers [4] with touch- and deformation-sensing capabilities are available as research demonstrators or commercial products, such as Levi's® jacket with Google's Jacquard™ technology [10]. The interaction and functional scope of such garment-integrated controls, however, are yet limited since they lack direct visual feedback and are thereby mostly used for simple system control tasks with predefined interaction mappings or for fast micro-interactions in an eyes-free manner.

In our work, we aim to maintain the promising and unobtrusive characteristics of body-worn E-Textiles and simultaneously want to support more generic and complex interfaces by providing a wearable, united input/output (I/O) space. Therefore, we want to utilize the visual capabilities of emerging AR glasses, such as the Microsoft HoloLens[1], to seamlessly extend body-worn, interactive fabrics with task-specific visual overlays that allow to control widgets in a more flexible, dynamic and guided way (see Figure 1, A+B). For our mobile context, we aim to visually enhance touch-enabled garment cords (see Figure 1, C), since they already exist in many everyday clothes, require minimal activation time, have many interesting physical affordances [12], and provide a rich, body-related interaction space [6].

[1] Microsoft HoloLens. https://www.microsoft.com/hololens

Related Work

While research has shown that body-worn cords have a promising potential for mobile interactions [12], there has been only little research on how interactive cords can be visually enhanced [2]. Previous research uses cords, strings and tapes as a decoupled ***input device*** (see Figure 2, **A**). Therefore, researchers investigated how *cord manipulation techniques* (**A1**), like twisting or pinching a cord [12, 11, 6], *spatial interactions* (**A2**), such as the deflection and pulling [2, 7, 9, 6], or *additional cord-attached controls* (**A3**) (e.g., buttons or joysticks [7, 9, 6]) can be used without visual feedback or with ***output devices*** (see Figure 2, **B**).

For example, Schwarz et al. [12] presented a cord sensor that is built with conductive yarn, capacitive sensing and a rotary encoder supporting twist, pull and touch actions for eyes-free smartphone controls (**B1**). In addition, Schoessler et al. [11] investigated conductive yarns, polymers, and piezo copolymer cables to utilize cords that are connected to everyday electrical devices (**B2**), such as lamps. As the only work considering visually augmented cords, which is also the focus of our work, Blasko et al. [2] presented the idea of cord-integrated LEDs that are attached to a wrist-worn dual-display (**B3**) providing access to spatial associated cells and items. While the authors built a projector-based proof-of-concept prototype, a broader usage for advanced visualization and interfaces are not discussed. In addition, Koch & Witt [7] control a selection grid on a generic screen (**B4**) using the position of a chest-worn cord, while Pohl et al. [9] used a retractable belt-worn e-ink badge at the end of the string to support indoor navigation (**B5**). Further on, in [6] we introduced a generic belt-worn controller with exchangeable knob controls and already argued that body-worn retractable string controllers have a promising potential for AR glasses (**B6**). However, we have not discussed a seamlessly united I/O cord interface yet.

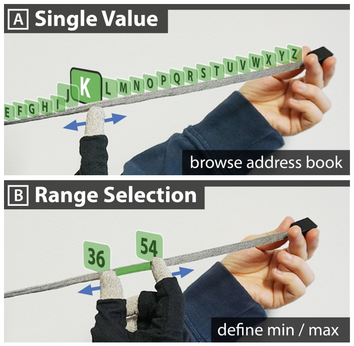

Figure 3: Single and Range Selection: As an example, address cards can be browsed alphabetically by simply sliding **(A)**. Multi-touch input, like pinching, allows to define precise ranges **(B)** with our gloves (see also Figure 8).

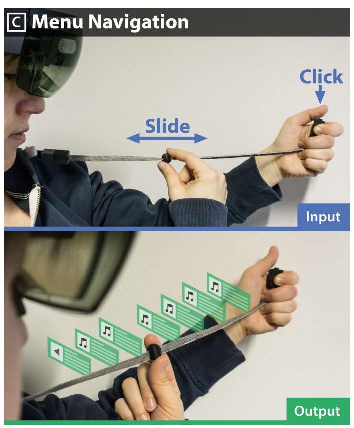

Figure 4: Menu Navigation: To play a specific song or album, the body-worn cord can be used for visually direct selections with the moveable slider (**C**) or by touch (similar as shown in Figure 3, A).

Finally, when looking at the visual augmentation of everyday objects, the concept of *opportunistic controls* by Henderson & Feiner [5] is also related to our work. Opportunistic controls support gesturing on, and receiving feedback from, otherwise unused affordances already present in a physical domain. In a similar sense, we plan to utilze already present fabric affordances that we aim to enhance with visual augmentations for mobile controls.

ARCord – Our Design

Our design focuses on the combination of the unique advantages of garment-integrated E-Textile cords and the dynamic visual output capabilities of emerging AR glasses. With this novel combination, we want to provide mobile user interfaces that are well suited to fulfil the increasing needs of unobtrusive and powerful mobile controls.

Therefore, our concept provides a wearable system in which a user can easily grab a garment-integrated cord, pull it away from the body and thereby open a cord-attached visual interface for mobile services that can be seamlessly controlled by two modes of interaction (see Figure 1, A+B). First, we aim to enhance body-worn hoodie or coat cords (similar to [13, 12]) with touch sensing capabilities (B) to lay the basis for our visually augmented cord controls. As a second input modality, we also envision the use of a cord toggle acting as a moveable value slider (Figure 1, A). Further, we propose the use of an additional tactile button at the end of the cord enabling explicit confirmations. To investigate on the design options for cord-related visual feedback, we want to consider *in-situ visuals* that are shown in-place as well as *cord-associated* AR visualizations that are loosely coupled. In summary, our system consists of a touch-sensitive, garment-integrated cord – representing a promising smart fabric sensor – and head-worn AR glasses that provide dynamic visual feedback for our cord controls.

ARCord – Interactive Visual Cord Controls

Selection, manipulation and navigation are well-known and frequent interaction tasks for mobile user interfaces. This section describes how our visually augmented cord control can be used to support (1) precise *single value and range selections* for adjusting parameters, (2) *menu navigation* for choosing options or switching states and (3) *selections of virtual or real objects in mixed-reality environments*.

Single Value & Range Selection

The affordance of a cord and its linear degree of freedom nicely maps to adjusting values and ranges (see Figure 3).

Single Value Selection. We utilize the cord for browsing and adjusting one-dimensional data structures, such as lists, stacks or numerical scales. Therefore, all data items and control widgets immediately appear as holographic AR overlays spatially attached to the cord (Figure 3, A). To keep the input simple, we use a *touch + click* approach in which the user directly selects items by touching on the visually augmented cord or moving the cord toggle. Confirmations are done by pressing the button at the cord's end.

Range Selection. Many applications require range selections, where multiple items are marked simultaneously or value ranges are selected (e.g. for filter settings). We support the *selection of ranges* using a *touch + hold* approach to define a minimum and maximum. Therefore, a user directly touches the first value and moves to the second value while holding the confirmation button. In addition, we provide the possibility of using multi-touch input to span and moving a range on the cord by pinching fingers (Figure 3, B). To seamlessly realize multi-touch input on the cord, we currently use gloves with conductive fingertips (see Figure 8). This could also be used for non-linear scaling, such as for zooming in a specific region of a timeline or numerical list making the cord interface more dynamic and flexible.

Figure 5: Ray Casting: Cord pointing allows to select all objects of a group, e.g. books of a book shelf. The result is shown at the cord clipboard **(D)**.

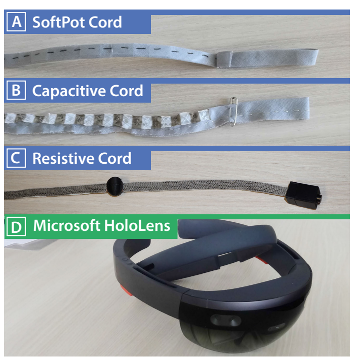

Figure 6: Our current prototype consists of a series of cord sensors **(A-C)** that are able to sense touch input and a Microsoft HoloLens **(D)** for the visualization.

Menu Navigation

Based on the previously introduced selection techniques, our approach also supports the control of linear menus (see Figure 4, C) using the same interaction pattern. In contrast to Schwarz et al. [12], who use predefined cord mappings and zones supporting eyes-free interaction, we support menu navigation by providing visual feedback on the cord itself in real-time for more complex and dynamic menus. Our direct interaction approach with directly coupled input and output modalities will thereby allow to build menu interfaces that can be seamlessly controlled without the need to learn predefined interaction schemes. Therefore, the physical cord acts as a wearable dock with dynamically attached menu icons to seamlessly access and control mobile apps and services, such as contact (see Figure 3, A) or music lists (see Figure 4) providing a high degree of flexibility.

Object Selection in Mixed-reality Environments

Finally, we want to introduce a technique for the selection of virtual or real objects in mixed-reality environments utilizing the cord as a physical pointer and dynamic container clipboard (see Figure 5, D). In this mode, the cord uses a visually augmented ray casting method to select objects or object groups in a distance. Therefore, the hoodie-worn cord origin acts as the point of reference of the ray. In contrast to head-coupled gaze-cursors, this cord pointing method allows more peripheral pointing interactions without the need of moving the head. Therefore, the user can directly point with the body-worn cord to an object and press the confirmation button. As a consequence the selected objects appear as small proxy elements at the cord and can be used or stored for further work. This technique can also be helpful for a multi-stage selection process in which the user first selects a group and then refines the selection on the cord.

Current Prototype

For our concepts, we basically need to realize:
(1) a flexible, wearable *(multi-)touch-enabled cord sensor*,
(2) a native *sensor communication* to the AR glasses,
(3) the *tracking of the cord in the AR coordinate system* and
(4) the implementation of the *cord AR application* itself.

The following section describes the current state of our implementation and gives insights in the design process.

Cord Sensor: We fabricated three touch-enabled cord sensors to lay a solid basis for our novel visually augmented cord approach (see Figure 6, A-C). Our first sensor (A) represents a high-precision and comparable baseline realization based on a commercial membrane potentiometer[2] that is sewn in a fabric cord and captures squeeze positions. The second sensor (B) integrates twelve capacitive pads that are sensed with a NXP® MPR121 chip and are made of multi-conductor zebra fabric[3] and conductive yarn allowing multi-touch recognition without any instrumentation. Our most promising cord sensor (C), which is inspired by Stern [13], uses a tiny moveable ring slider on a resistive cord (see also Figure 7). To avoid a separate measurement cord on the moveable slider (cf. [13]), we fabricated a novel, custom-made double-sided cord. The sensor consists of a resistive layer (see Figure 7, A), followed by an isolation layer (B) with integrated power and button cables (C) and a measuring track layer (D). A moveable slider ring (E) bridges both layers and creates a unique resistance depending on its current position. Further, this cord also supports multi-touch input with special gloves (Figure 8). The fingertips of the glove acts as measuring lines on the cord's resistive track. In addition, we integrate a tactile button at the end of the cord that can be used to confirm selections.

[2] Spectral Symbol, SoftPot Membrane Potentiometer. http://www.spectrasymbol.com/product/thinpot/
[3] HITEK, Zebra Fabric. https://www.hitek-ltd.co.uk

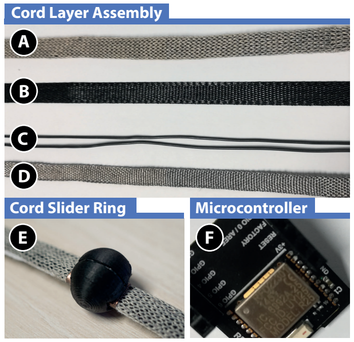

Figure 7: Our resistive cord sensor consists of a resistive cord **(A)**, a divider layer **(B)**, two ultra-thin wires **(C)** and a conductive layer **(D)**. A BLE-enabled microcontroller **(E)** senses the position of the touch or cord slider ring **(F)** that bridges the resistive with the conductive layer.

Figure 8: Our optional gloves can be used for multi-touch input and finger identification capabilities for our interactive cords. All fingertips are made of highly conductive fabrics that can act as sensing lines at our resistive cord track.

Microcontroller & Communication: To realize our prototypes, we used a tiny nRF51822[4] microcontroller (see Figure 7, F) with built-in Bluetooth Low Energy (BLE) and 10bit analog-to-digital sensing capabilities. The chip is powered by a 400mAh LiPo battery. For the communication, we built on custom BLE peripherals and implemented value characteristics based on the Generic Attribute Profile (GATT) to provide a native wireless connection to our AR glasses.

Dynamic Cord Tracking: To dynamically place holograms on (or directly attached to) the freely movable cord, it is necessary to locate the cords position in the coordinate system of the AR glasses. Since dynamic object tracking is not natively supported by current AR glasses, a challenge is to implement a dynamic cord tracker. This could be done, for instance, by using a camera-based approach that uses the front camera for image processing. In this method, the main challenge will be to track the cord and align the visual controls with low computing power. An alternative could be the development of a deformation self-sensing (cf. [1, 3]) flexible cord sensor or to use cord-attached IR-marker with an external optical tracking in the next iteration. At its current stage, we statically place all holographic controls in front of the user. Even though the tracking has yet to be implemented, this method gives us a good starting point.

AR Glasses Application: For our ARCord implementation, we use the Microsoft HoloLens (Figure 6, D) as a representative of state-of-the-art AR glasses. Our framework uses the Unity game engine with C# and natively supports a wireless connection. All received cord sensor values are already being handled and trigger new events, such as the translation of holographic controls or call of new menu levels. Further information are available at our website[5].

[4] Nordic Semiconductor, nRF51822 SoC. https://www.nordicsemi.com/eng/Products/Bluetooth-low-energy/nRF51822/

[5] ARCord project website: https://imld.de/arcord/

Conclusion & Future Work

We presented the concept of visually augmented, interactive cords using state-of-the-art AR glasses. Therefore, we introduced a set of interaction techniques that extends mobile AR interactions (e.g., eye gaze, gesture and voice control) by providing a body-centric cord sensor that enables an unobtrusive, haptic and visual interface supporting fundamental mobile control tasks. While our techniques require two hands, we assume that this is not a problem for short sequences of simple actions. However, this is an interesting aspect for future studies. Finally, we describe all necessary steps to implement our concepts and have already realized a majority of them including the fabrication of touch-enabled and moveable slider cords, its seamless connection to the HoloLens and initial interactive visualizations.

For future work, we plan to conduct an in-the-wild study comparing the usability and obtrusiveness between our cord interface and current solutions, such as mid-air gestures. To do so, we will have to finish a cord tracking and implement a real-world application (e.g., smart city guide).

Acknowledgements: We thank Eva Morawietz for her conceptual work, initial prototypes and valuable discussions. This work was in part funded by grant no. 03ZZ0514C of the German Federal Ministry of Education and Research.

REFERENCES

1. Ravin Balakrishnan, George Fitzmaurice, Gordon Kurtenbach, and Karan Singh. 1999. Exploring Interactive Curve and Surface Manipulation Using a Bend and Twist Sensitive Input Strip. In *Proc. of I3D '99*. ACM, New York, NY, USA, 111–118. DOI: http://dx.doi.org/10.1145/300523.300536

2. Gabor Blasko, Chandra Narayanaswami, and Steven Feiner. 2006. Prototyping Retractable String-based Interaction Techniques for Dual-display Mobile Devices.

In *Proc. of CHI '06*. ACM, New York, NY, USA, 369–372. DOI: http://dx.doi.org/10.1145/1124772.1124827

3. Artem Dementyev, Hsin-Liu (Cindy) Kao, and Joseph A. Paradiso. 2015. SensorTape: Modular and Programmable 3D-Aware Dense Sensor Network on a Tape. In *Proc. of UIST '15*. ACM, New York, NY, USA, 649–658. DOI: http://dx.doi.org/10.1145/2807442.2807507
4. David Dobbelstein, Christian Winkler, Gabriel Haas, and Enrico Rukzio. 2017. PocketThumb: A Wearable Dual-Sided Touch Interface for Cursor-based Control of Smart-Eyewear. *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.* 1, 2, Article 9 (June 2017), 17 pages. DOI: http://dx.doi.org/10.1145/3090055
5. Steven Henderson and Steven Feiner. 2010. Opportunistic Tangible User Interfaces for Augmented Reality. *IEEE TVCG* 16, 1 (Jan 2010), 4–16. DOI: http://dx.doi.org/10.1109/TVCG.2009.91
6. Konstantin Klamka and Raimund Dachselt. 2015. Elasticcon: Elastic Controllers for Casual Interaction. In *Proc. of MobileHCI '15*. ACM, New York, NY, USA, 410–419. DOI: http://dx.doi.org/10.1145/2785830.2785849
7. Erik Koch and Hendrik Witt. 2008. Prototyping a chest-worn string-based wearable input device. In *WoWMoM 2008*. 1–6. DOI: http://dx.doi.org/10.1109/WOWMOM.2008.4594882
8. Patrick Parzer, Adwait Sharma, Anita Vogl, Jürgen Steimle, Alex Olwal, and Michael Haller. 2017. SmartSleeve: Real-time Sensing of Surface and Deformation Gestures on Flexible, Interactive Textiles, Using a Hybrid Gesture Detection Pipeline. In *Proc. of UIST '17*. ACM, New York, NY, USA, 565–577. DOI: http://dx.doi.org/10.1145/3126594.3126652
9. Norman Pohl, Steve Hodges, John Helmes, Nicolas Villar, and Tim Paek. 2013. An Interactive Belt-worn Badge with a Retractable String-based Input Mechanism. In *Proc. of CHI '13*. ACM, New York, NY, USA, 1465–1468. DOI: http://dx.doi.org/10.1145/2470654.2466194
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 *Proc. of CHI '16*. ACM, New York, NY, USA, 4216–4227. DOI: http://dx.doi.org/10.1145/2858036.2858176
11. Philipp Schoessler, Sang-won Leigh, Krithika Jagannath, Patrick van Hoof, and Hiroshi Ishii. 2015. Cord UIs: Controlling Devices with Augmented Cables. In *Proc. of TEI '15*. ACM, New York, NY, USA, 395–398. DOI: http://dx.doi.org/10.1145/2677199.2680601
12. Julia Schwarz, Chris Harrison, Scott Hudson, and Jennifer Mankoff. 2010. Cord Input: An Intuitive, High-accuracy, Multi-degree-of-freedom Input Method for Mobile Devices. In *Proc. of CHI '10*. ACM, New York, NY, USA, 1657–1660. DOI: http://dx.doi.org/10.1145/1753326.1753573
13. Becky Stern. 2015. Textile Potentiometer Hoodie - All-sewn slide-sensor circuit. (2015). https://learn.adafruit.com/textile-potentiometer-hoodie/overview
14. Martin Weigel and Jürgen Steimle. 2017. DeformWear: Deformation Input on Tiny Wearable Devices. *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.* 1, 2, Article 28 (June 2017), 23 pages. DOI: http://dx.doi.org/10.1145/3090093