Mobile Interactions Augmented by Wearable Computing: A Design Space and Vision

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Mobile Interactions Augmented by Wearable Computing: a Design Space and Vision

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ABSTRACT

Wearable computing has a huge potential to shape the way we interact with mobile devices in the future. Interaction with mobile devices is still mainly limited to visual output and tactile finger-based input. Despite the visions of next-generation mobile interaction, the hand-held form factor hinders new interaction techniques becoming commonplace. In contrast, wearable devices and sensors are intended for more continuous and close-to-body use. This makes it possible to design novel wearable-augmented mobile interaction methods – both explicit and implicit. For example, the EEG signal from a wearable breast strap could be used to identify user status and change the device state accordingly (implicit) and the optical tracking with a head-mounted camera could be used to recognize gestural input (explicit). In this paper, we outline the design space for how the existing and envisioned wearable devices and sensors could augment mobile interaction techniques. Based on designs and discussions in a recently organized workshop on the topic as well as other related work, we present an overview of this design space and highlight some use cases that underline the potential therein.

KEYWORDS

Wearable Computing; Design Space; Mobile Interaction

INTRODUCTION

During the development of mobile phones and other mobile information devices, also the input and output methods have gradually changed. The early mobile phones used to have only physical buttons for tactile input and a small monochrome display for visual output. Over the last decade, with the introduction of smart phones, the archetype of a mobile device has turned into a sensor-rich device that features large touch screens, greatly increased computational power, and, most importantly, built-in sensors such as accelerometers, gyroscopes, and GPS (Hinckley, Pierce, Sinclair, & Horvitz, 2000). After the touch screen revolution the sensors have enriched the interaction possibilities, allowing, for example,

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moving the phone in mid-air for gestural interaction or tracking users' physical activity while having the phone in the pocket.

Despite the rapid progress, the form factor of mobile phones is still a limitation. They are hand-held devices and the main explicit input method still involves holding the phone in the one and interacting with the other hand. In other words, much of the sensors and other capabilities remain underutilized by current applications and interaction techniques, partly because of the handheld form factor.

Fortunate for developers of new interaction techniques, the rapidly evolving wearable devices are slowly entering the market with not only more and better sensors but also more opportune form factors and body locations. Wearable devices and peripherals, such as fitness bracelets, breast straps, wrist-worn devices, or head-mounted devices allow for new types of close-to-body interactions. Moving even closer to the body, smart garments allow placing sensors and actuators unobtrusively close to the human body. However, the gap between the products that arrive at the mass market and the envisioned research prototypes is still huge. Wearable computers have a history which already started back in the 1960s. Thorps wearable computer was able to calculate roulette probabilities (Thorp, 1998). Since then a number of different devices have been built realizing a variety of applications. Garments measuring the physiological properties of the user (Gopalsamy, Park, Rajamanickam, & Jayaraman, 1999), belts detecting the user's posture (Farringdon, Moore, Tilbury, Church, & Biemond, 1999), or wearable displays showing information about the user (Falk & Björk, 1999) have all been explored in the last millennium. More than 15 years later, almost none of these prototypically developed devices achieved success in the mass market.

What is currently particularly interesting is the potential in combining wearable and hand-held devices: the hand-held smart devices have vast computation capabilities and connectivity, while the wearable sensors and actuators can be placed at various parts of the body to allow more direct, accurate and always accessible input/output. Looking at the successful devices that are currently available at the mass market such as fitness bracelets or heart rate monitoring devices, it becomes apparent that these devices are actually external sensors that increase the sensing capability of the users' smartphone and most of the time not fully functional stand-alone systems. These devices mainly fulfill basic use-cases and applications, nowadays mainly in the fitness and eHealth domain, but are not restricted to them.

In fact, there are hundreds of smartphone applications that utilize these sensors to expand the variety of use cases and applications to different domains. To facilitate this transition, the integration from the wearable device to the user's mobile ecosystem is one of the success criteria for wearable devices. This motivates to investigate a new design space for mobile interaction that takes into account the sensing and actuating capabilities beyond smartphones. While current smartphone applications deal with the limited sensing and actuating capabilities as well as limited placement possibilities offered by smartphones of today, wearable devices can augment these possibilities. In contrast to using touch and voice input of the device itself, an unlimited number of sensors and actuators connected to one's mobile device can be used, allowing various novel applications and interactions to be envisioned and realized.

In the remainder of the paper, we first present the design space and discuss each of the dimensions, then we highlight four use-cases and a graphical representation of the design space, and finally we discuss aspects of research that need to be considered.

THE DESIGN SPACE OF WEARABLE-AUGMENTED INTERACTION

Since the interaction possibilities of mobile phones are limited, wearable computing creates a much broader design space for input and output technology. In the following, we present the design space for wearable devices that can be used to augment mobile interaction. This design space is based on an extensive review of products and literature. We present a matrix presentation of the design space (Figure 1) and discuss each of the dimensions.

Effectively Utilizing the Human Body Area

An important design consideration for wearable computing devices is the body part on which the sensors, actuators, and processing unit are placed. We differentiate between six different parts of the body and external systems. The body parts are segmented into upper body (hands, arms, torso, and head) and lower body (legs and feet). Specific sensors need to be placed at specific positions on the user's body. Physiological input, for example, needs to be measured at specific parts to sense the desired physiological properties. Accelerometers for detecting the activity of the user needs to be placed at dedicated locations distributed on the users body (Bao & Intille, 2004) and a wristband for detecting the hand movement of the right hand needs to be placed exactly at this location (Cheng, Bahle, & Lukowicz, 2012). On the other hand, to actuate specific parts of the body, the actuators need to be placed at the respective location or at the muscle responsible for the desired actuation. Vibrational feedback, for instance, at the arm requires the placement of a vibrational engine exactly at the dedicated location, that is, the arm. However, when actuating the users hands using electrical muscle stimulation, the electrodes need to be placed at the arm (Lopes, Jonell, & Baudisch, 2015) and turning the legs for changing the walking direction requires a placement of the electrode on the inner side of the legs (Pfeiffer, Dünte, Schneegass, Alt, & Rohs, 2015). Thus, the body part that is used needs to fit the use-case of the devices but the destination of sensing and actuation is not always the same location the sensor or actuator is placed. This can be further explored during the development process, for example, through user-centered design (Alhonsuo, Hapuli, Virtanen, Colley, & Häkkilä, 2015).

Input

Most wearable computing devices focus either on input or on output, and the ones focusing on input are in the majority. Devices focusing on input strive to detect the users activity, posture, or explicit input. This can be sensed through three different classes of sensing mechanism. First, physical movement generates pressure or movement that can be sensed through, for example, pressure sensor (Zhou, Cheng, Sundholm, & Lukowicz, 2014) or strain sensors (Lorussi, Rocchia, Scilingo, Tognetti, & De Rossi, 2004). This can be used to detect, for instance, the posture (Lorussi et al., 2004), performed gesture (Cheng et al., 2012), or activity (Bao & Intille, 2004) of the user. By moving his or her body, the user physically generates pressure that is sensed by pressure sensors or changes the posture that forces stretch sensors to expand. Second, changes in the physiological properties of the human body can be detected. This includes Electrocardiography (ECG) or the body temperature of the user. Especially garment based systems are used to measure physiological properties due to the close and fixed connection between body and sensor. Several systems show that measuring ECG (Firoozbakhsh, Jayant, Park, & Jayaraman, 2000) or respiratory frequency (Di Rienzo et al., 2005) is possible and beneficial for mobile health-care applications. Carpi and De Rossi present an overview and background knowledge on smart textiles and smart garments as well as their opportunities (Carpi & De Rossi, 2005). In addition to health-care applications, such sensors enable systems by detecting changes in the physiological state of the user to adapt services to the current needs (e.g., simplify a User Interface while the user is strained (Schneegass, Pfleging, Broy, Heinrich, & Schmidt, 2013)). Last, a system can sense contextual data from the environment the user currently is in. Examples range from environmental audio from integrated microphones (Lukowicz et al., 2004) to QR codes scanned through head-mounted camera which can all be used to enhance the mobile interaction.

Output

On the output side, the wearable computing device gives feedback to the user mainly using visual or auditory cues. Visual output can be either designed for the users themselves (Farion & Purver, 2013) or as an output medium for others as a public (Sasaki, Terada, & Tsukamoto, 2013). The visual output ranges from color changing fabric (Kuusk, Kooroshnia, & Mikkonen, 2015), small LEDs embedded into bracelets (Fortmann, Cobus, Heuten, & Boll, 2014) or clothing (Senol, Akkan, Bulgun, & Kayacan, 2011) to rich displays that can be placed somewhere on the body (Falk & Björk, 1999; Olberding, Yeo, Nanayakkara, & Steimle, 2013). While auditory feedback can be used for notification or entertainment similar to visual feedback, it can also be exploited for purposes such as user identification and authentication (Schneegass, Oualil, & Bulling, 2016). Additionally, the usage of physical actuators such as vibrational feedback (Heuten, Henze, Boll, & Pielot, 2008) or feedback through Electric Muscle Stimulation (EMS) provides feedback to users (Pfeiffer, Schneegass, Alt, & Rohs, 2014). It provides feedback to the user directly at the intended position, for example, to enhance the posture of the user (Wang et al., 2015) or to give directional cues

(Mateevitsi, Haggadone, Leigh, Kunzer, & Kenyon, 2013). In addition to that, some types of output are used to create physiological output. These systems directly manipulate the human body. Examples include EMS to directly manipulate the user's muscles (Lopes et al., 2015; Pfeiffer et al., 2015) or changing the body temperature (Jagodzinski, Wintergerst, & Giles, 2012). Last, the contextual output is used for systems that is not limited to wearable output itself but used the mobile phone or other systems (e.g., a public display (Schneegass, 2015)) as output medium. An important aspect is the combination of several output devices such as several displays (Grubert, Kranz, & Quigley, 2015) creating novel experiences for the user.

Design Space Visualization and Use-Cases

Because of the rapidly increasing capabilities of both mobile and wearable devices there are numerous possible use cases in which wearable sensors could augment the input or output in mobile interaction. Based on contributions to a recently organized workshop, we highlight four use cases to show how mobile interaction can benefit from the capabilities of wearable devices. In addition, we classify these use-cases on the visual representation of the design space (Figure 1).

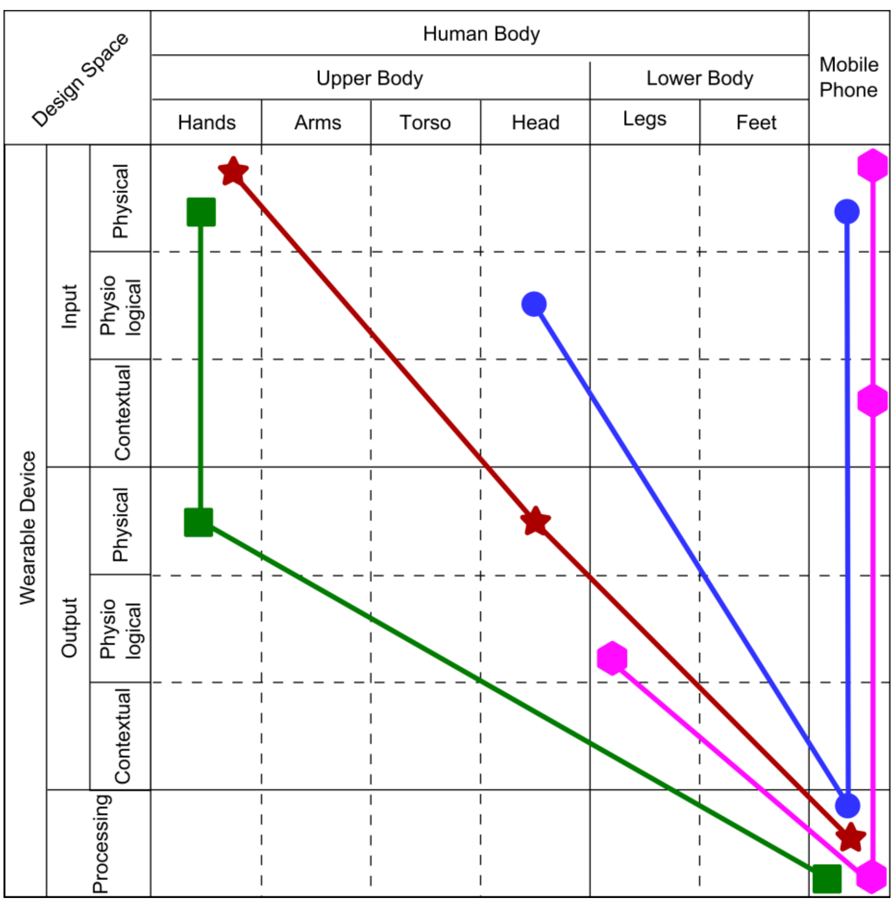

Figure 1: The visual representation of the Design Space. The four use cases are included: Head Mounted Display (red star), Brain Computer Interface (blue circle), Interaction with a Cone (green square), and Haptic Navigation (pink triangle).

Head-Mounted Displays extending the Visual Output

Head-mounted displays such as the Google Glass provide the user with a private display. While these displays are nowadays used to display notifications and requested information, their possibilities in augmenting mobile interaction can tackle many challenges by exploiting the private, near eye display for interaction. This display, for instance, can be used to augment interaction on the users palm by displaying interfaces on the near-eye display over the users palm (Müller, Dezfuli, Mühlhäuser, Schmitz, & Khalilbeigi, 2015) ensuring the privacy of the user. The security of mobile devices can be increased by providing secret information that can only be seen by the user. This information can be used to modify the login procedure so that the password cannot be stolen using shoulder surfing (Winkler et al., 2015).

Brain Computer Interfaces for Implicit Input

Brain Computer Interfaces measure the brain activity and derive a cognitive state of the user. In contrast to information about the users activity such as step count, this information can be used to quantify not only the user‘s bodily functions but also the cognitive ones. Relaxation, concentration, and engagement are just examples of states that can be derived and be valuable information to adopt the interaction (Hassib & Schneegass, 2015). Current Brain Computer Interfaces are designed in a way that they are already easy to set up and contain different communication possibilities. However, the integration with other applications is neither standardized nor easily doable.

Mobile Interaction for Visually Impaired Users

Current mobile devices use mechanisms to change the content that is designed for visual output to auditory output for visually impaired users (i.e., by using text-to-speech functionality). Auditory output, however, may not be easily usable in all environments so that tactile output spatially distributed on the body may be used to overcome this issue. Another approach is enriching the cane visually impaired people use for navigating through smartphones interfaces (Avila & Kubitza, 2015). The cane can be used as an input mean (e.g., making the surface touch sensitive) and as output mean (e.g., vibrating the cane).

Haptic Navigation

Electrical Muscle Stimulation has the potential to not only provide feedback but also actuate muscles so that the user performs certain movements. When EMS is applied to the muscles in the leg, the rotation angle of the leg can easily be controlled (Pfeiffer et al., 2015). The rotation of the leg implicitly lets the user walk into a certain direction that can be controlled by the EMS. Augmenting a mobile navigation system with such an actuator, the user does not need to watch the display or auditory cues but can just focus on the environment and is automatically steered. The mobile phone provides information on the destination and location (e.g., via GPS) and offers the computational capabilities to calculate the intensity of EMS.

RESEARCH CONSIDERATIONS

Moving the research on the integration of mobile and wearable interaction forwards, three main aspects need to be considered.

Integration of Wearable and Mobile Devices Requires Broad Skills

Wearable devices are complex products that require different types of expertise in design and manufacturing compared to traditional electronic consumer devices. Developing electronics, algorithms, and interaction concepts are just the main steps that need to be taken to create these devices. Each of these steps needs a specific expertise that barely overlaps. Experts in creating electronics may have a basic understanding of creating usable and pleasurable interaction concepts but are typically not experts in it. However, the expertise in all fields is needed to create a product that benefits the user. Thus, interfaces between hardware, software, and user interface need to be designed to separate the concern of a single wearable device. While sensor developers provide interfaces of the raw sensor data to middleware, experts in the creation of algorithm can use this data to create meaningful information such as physiological user data or detected actions (Schneegass, Hassib, Birmili, & Henze, 2014). In the next step, this information can further be utilized in applications that are well designed and well fitted to the needs of the users.

Unobtrusiveness and Ubiquity: From Wearable Gadgets to Smart Garments

In addition to wearable gadgets such as bracelets and goggles, smart garments yield high potential of augmenting mobile interaction. Different types of garments have been suggested with a wide variety of sensing and actuating capabilities. Examples for smart garments include the Wealthy system (Paradiso, Loriga, & Taccini, 2005) or the SmartShirt (Lee & Chung, 2009), which both include different sensing and communication capabilities that could be used to augment mobile interaction. The potential of garments is huge due to their pervasiveness in our lives: we use garments on every day of our life from the day of birth on. Furthermore, physiological parameters can be easily measured since garments cover the distinct locations on the body. This allows, for example, providing a holistic overview of a user's health status with ECG measurement over years. In contrast to wearable gadgets, garments require further knowledge in the manufacturing process that needs to be acquired to create products rather than prototypes. Mass-produce, fashion, and comfort are only three out of many requirements that that need special attention when developing garment based wearable computers.

Ecologic Validity: Evaluation of Wearable Devices in the Wild

The most common research methodology for wearable computing is probe-based research. Looking at the common methodologies in mobile human-computer interaction, field studies and deployment based research gains more and more popularity (Henze, Sahami, Schmidt, Pielot, & Michahelles, 2013). Both types of research are important to better understand wearables in ecologic valid settings. Obviously, the distribution of software is much easier compared to hardware but to achieve ecologically valid research results field and deployment-based research needs to gain more attention. Further, robustness of newly created wearable devices and necessity to create multiple devices for studies in ecologically valid environments (Väänänen-Vainio-Mattila, Olsson, & Häkkilä, 2015) (i.e., during everyday life for at least a couple of days) needs to increased compared to a prototype used for laboratory evaluations.

A first approach is exploiting wearable devices that already hit the mass market such as fitness bracelets and smartwatches (Schlögl, Buricic, & Pycha, 2015). While these devices are connected to smartphones, the communication and data storage can easily be achieved through them. However, the number of wearables is limited but it is a first starting point to further explore new evaluation methods for wearable devices.

CONCLUSIONS

The integration of wearable devices into the mobile phone of the user yields huge potential for augmenting the current interaction techniques. By exploiting the unique sensing and actuating potential of wearables, the design space for mobile interactions is extended from the tip of the finger to the whole body. In addition to the mainly explicit input, various implicit input possibilities can be realized. In this paper, we outlined a design space for mobile interaction augmented with wearable computing. We presented four use cases as concrete demonstrators of how already the currently available off-the-shelf wearables or research prototypes can be used to augment the mobile human-computer interaction.

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REFERENCES

Alhonsuo, M., Hapuli, J., Virtanen, L., Colley, A., & H¨akkil¨a, J. (2015). Concepting Wearables for Ice-Hockey Youth. In Proceedings of the 17th international conference on human-computer interaction with mobile devices and services adjunct (pp. 944–946). New York, NY, USA: ACM.

Avila, M., & Kubitza, T. (2015). Assistive Wearable Technology for Visually Impaired. In Proceedings of the 17th international conference on humancomputer interaction with mobile devices and services adjunct (pp. 940–943). New York, NY, USA: ACM.

Bao, L., & Intille, S. S. (2004). Activity Recognition from User-Annotated Acceleration Data. In A. Ferscha & F. Mattern (Eds.), Pervasive computing (Vol. 3001, pp. 1–17). Springer Berlin Heidelberg.

Carpi, F., & De Rossi, D. (2005). Electroactive polymer-based devices for e-textiles in biomedicine. IEEE Transactions on Information Technology in Biomedicine, 9(3), 295–318.

Cheng, J., Bahle, G., & Lukowicz, P. (2012, October). A simple wristband based on capacitive sensors for recognition of complex hand motions. In 2012 ieee sensors (pp. 1–4). IEEE.

Di Rienzo, M., Rizzo, F., Parati, G., Brambilla, G., Ferratini, M., & Castiglioni, P. (2005). MagIC System: a New Textile-Based Wearable Device for Biological Signal Monitoring. Applicability in Daily Life and Clinical Setting. In Engineering in medicine and biology society, 2005. ieee-embs 2005. 27th annual international conference of the (pp. 7167–7169).

Senol, Y., Akkan, T., Bulgun, E. Y., & Kayacan, O. (2011). Active T-shirt. International Journal of Clothing Science and Technology, 23(4), 249–257.

Falk, J., & Bj¨ork, S. (1999). The BubbleBadge: A Wearable Public Display. In Chi ’99 extended abstracts on human factors in computing systems (pp. 318–319). New York, NY, USA: ACM.

Farion, C., & Purver, M. (2013). Message Bag: Can Assistive Technology Combat Forgetfulness? In Proceedings of the 4th augmented human international conference (pp. 134–137). New York, NY, USA: ACM.

Farringdon, J., Moore, A. J., Tilbury, N., Church, J., & Biemond, P. D. (1999). Wearable sensor badge and sensor jacket for context awareness. In Wearable computers, 1999. digest of papers. the third international symposium on (pp. 107–113).

Firoozbakhsh, B., Jayant, N., Park, S., & Jayaraman, S. (2000). Wireless communication of vital signs using the Georgia Tech Wearable Motherboard. In Multimedia and expo, 2000. icme 2000. 2000 ieee international conference on (Vol. 3, pp. 1253–1256 vol.3).

Fortmann, J., Cobus, V., Heuten, W., & Boll, S. (2014). WaterJewel: Design and Evaluation of a Bracelet to Promote a Better Drinking Behaviour. In Proceedings of the 13th international conference on mobile and ubiquitous multimedia (pp. 58–67). New York, NY, USA: ACM.

Gopalsamy, C., Park, S., Rajamanickam, R., & Jayaraman, S. (1999). TheWearable Motherboard?: The first generation of adaptive and responsive textile structures (ARTS) for medical applications. Virtual Reality, 4(3), 152–168.

Grubert, J., Kranz, M., & Quigley, A. (2015). Design and Technology Challenges for Body Proximate Display Ecosystems. In Proceedings of the 17th international conference on human-computer interaction with mobile devices and services adjunct (pp. 951–954). New York, NY, USA: ACM.

Hassib, M., & Schneegass, S. (2015). Brain Computer Interfaces for Mobile Interaction: Opportunities and Challenges. In Proceedings of the 17th in ternational conference on human-computer interaction with mobile devices and services adjunct (pp. 959–962). New York, NY, USA: ACM.

Henze, N., Shrazi, A. S., Schmidt, A., Pielot, M., & Michahelles, F. (2013). Empirical Research through Ubiquitous Data Collection. Computer, 46(6), 74–76.

Heuten, W., Henze, N., Boll, S., & Pielot, M. (2008). Tactile Wayfinder: A Nonvisual Support System for Wayfinding. In Proceedings of the 5th Nordic conference on human-computer interaction: Building bridges (pp. 172–181). New York, NY, USA: ACM.

Hinckley, K., Pierce, J., Sinclair, M., & Horvitz, E. (2000). Sensing Techniques for Mobile Interaction. In Proceedings of the 13th annual acm symposium on user interface software and technology (pp. 91–100). New York, NY, USA: ACM.

Jagodzinski, R., Wintergerst, G., & Giles, P. (2012). Thermal Display, based on the separated presentation of hot and cold. In H. Reiterer & O. Deussen (Eds.), Mensch & computer 2012 workshopband: interaktiv informiert allgegenwärtig und allumfassend!? (pp. 155–162). München: Oldenbourg Verlag.

Kuusk, K., Kooroshnia, M., & Mikkonen, J. (2015). Crafting Butterfly Lace: Conductive Multi-color Sensor-actuator Structure. In Adjunct proceedings of the 2015 acm international joint conference on pervasive and ubiquitous computing and proceedings of the 2015 acm international symposium on wearable computers (pp. 595–600). New York, NY, USA: ACM.

Lee, Y.-D., & Chung, W.-Y. (2009). Wireless sensor network based wearable smart shirt for ubiquitous health and activity monitoring. Sensors and Actuators B: Chemical, 140(2), 390–395.

Lopes, P., Jonell, P., & Baudisch, P. (2015). Affordance++: Allowing Objects to Communicate Dynamic Use. In Proceedings of the 33rd annual acm conference on human factors in computing systems (pp. 2515–2524). New York, NY, USA: ACM.

Lorussi, F., Rocchia, W., Scilingo, E. P., Tognetti, A., & De Rossi, D. (2004). Wearable, redundant fabric-based sensor arrays for reconstruction of body segment posture. IEEE Sensors Journal, 4(6), 807–818.

Lukowicz, P., Ward, J., Junker, H., Stäger, M., Tröster, G., Atrash, A., & Starner, T. (2004). Recognizing Workshop Activity Using Body Worn Microphones and Accelerometers. In A. Ferscha&F. Mattern (Eds.), Pervasive computing (Vol. 3001, pp. 18–32). Springer Berlin Heidelberg.

Mateevitsi, V., Haggadone, B., Leigh, J., Kunzer, B., & Kenyon, R. V. (2013). Sensing the Environment Through SpiderSense. In Proceedings of the 4th augmented human international conference (pp. 51–57). New York, NY, USA: ACM.

Müller, F., Dezfuli, N., Mühlhäuser, M., Schmitz, M., & Khalilbeigi, M. (2015). Palm-based Interaction with Head-mounted Displays. In Proceedings of the 17th international conference on human-computer interaction with mobile devices and services adjunct (pp. 963–965). New York, NY, USA: ACM.

Olberding, S., Yeo, K. P., Nanayakkara, S., & Steimle, J. (2013). AugmentedForearm: Exploring the Design Space of a Display-enhanced Forearm. In Proceedings of the 4th augmented human international conference (pp. 9–12). New York, NY, USA: ACM.

Paradiso, R., Loriga, G., & Taccini, N. (2005, September). A wearable health care system based on knitted integrated sensors. Information Technology in Biomedicine, IEEE Transactions on, 9(3), 337–344.

Pfeiffer, M., Dünte, T., Schneegass, S., Alt, F., & Rohs, M. (2015). Cruise Control for Pedestrians: Controlling Walking Direction using Electrical Muscle Stimulation. In ACM (Ed.), Proceedings of the sigchi conference on human factors in computing systems (to be published). New York, NY, USA: ACM.

Pfeiffer, M., Schneegass, S., Alt, F., & Rohs, M. (2014). Let Me Grab This: A Comparison of EMS and Vibration for Haptic Feedback in Free-Hand Interaction. In Proceedings of the 5th augmented human international conference.

Sasaki, H., Terada, T., & Tsukamoto, M. (2013). A System for Visualizing Human Behavior Based on Car Metaphors. In Proceedings of the 4th augmented human international conference (pp. 221–228). New York, NY, USA: ACM.

Schlögl, S., Buricic, J., & Pycha, M. (2015). Wearables in the Wild: Advocating Real-Life User Studies. In Proceedings of the 17th international conference on human-computer interaction with mobile devices and services adjunct (pp. 966–969). New York, NY, USA: ACM.

Schneegass, S. (2015). There is More to Interaction with Public Displays Than Kinect: Using Wearables to Interact with Public Displays. In Proceedings of the 4th international symposium on pervasive displays (pp. 243–244). New York, NY, USA: ACM.

Schneegass, S., Hassib, M., Birmili, T., & Henze, N. (2014). Towards a Garment OS: Supporting Application Development for Smart Garments. In Proceedings of the 2014 acm international symposium on wearable computers: Adjunct program (pp. 261–266). New York, NY, USA: ACM.

Schneegass, S., Mayer, S., Olsson, T., & Van Laerhoven, K. (2015). From Mobile to Wearable: Using Wearable Devices to Enrich Mobile Interaction. In Proceedings of the 17th international conference on human-computer interaction with mobile devices and services adjunct (pp. 936–939). New York, NY, USA: ACM.

Schneegass, S., Oualil, Y., & Bulling, A. (2016). SkullConduct: Biometric User Identification on Eyewear Computers Using Bone Conduction Through the Skull. In Proceedings of the sigchi conference on human factors in computing systems. New York, NY, USA: ACM.

Schneegass, S., Pfleging, B., Broy, N., Heinrich, F., & Schmidt, A. (2013). A data set of real world driving to assess driver workload. In Proceedings of the 5th international conference on automotive user interfaces and interactive vehicular applications (pp. 150–157).

Thorp, E. O. (1998). The invention of the first wearable computer. Second International Symposium on Wearable Computers, 4–8.

Väänänen-Vainio-Mattila, K., Olsson, T., & Häkkilä, J. (2015). Towards Deeper Understanding of User Experience with Ubiquitous Computing Systems: Systematic Literature Review and Design Framework. In J. Abascal, S. Barbosa, M. Fetter, T. Gross, P. Palanque, & M. Winckler (Eds.), Human-computer interaction interact 2015 (Vol. 9298, pp. 384–401). Springer International Publishing.

Wang, Q., Chen, W., Timmermans, A. A. A., Karachristos, C., Martens, J. B., & Markopoulos, P. (2015, August). Smart Rehabilitation Garment for posture monitoring. In Engineering in medicine and biology society (embc), 2015 37th annual international conference of the ieee (pp. 5736–5739).

Winkler, C., Gugenheimer, J., Luca, A. D., Haas, G., Dobbelstein, D., & Rukzio, E. (2015). Glass Unlock : Enhancing Security of Smartphone Unlocking through Leveraging a Private Near-eye Display. In Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems - CHI '15. New York, NY, USA: ACM.

Zhou, B., Cheng, J., Sundholm, M., & Lukowicz, P. (2014). From Smart Clothing to Smart Table Cloth: Design and Implementation of a Large Scale, Textile Pressure Matrix Sensor. In E. Maehle, K. Roemer, W. Karl, & E. Tovar (Eds.), Architecture of computing systems - arcs 2014 (Vol. 8350, pp. 159–170). Springer International Publishing.