Sensors in your Clothes: Design and Development of a Prototype

Kristine Lorentzen[2], Tor-Morten Grønli[2], Gheorghita Ghinea[1, 2], Muhammad Younas[3] and Manoranjan Satpathy[4]
[1]Brunel University, London, UK
[2]Westerdals Oslo ACT, Faculty of Technology, Oslo, Norway
[3] Oxford Brookes University, Oxford, UK
[4] Indian Institute of Technology, India

sunkri@westerdals.no, tmg@westerdals.no, george.ghinea@brunel.ac.uk, m.younas@brookes.ac.uk, nuapatana@gmail.com

Abstract
Wearable computing is fast advancing as a preferred approach for integrating software solutions not only in our environment, but also in our everyday garments to exploit the numerous information sources we constantly interact with. This paper explores this context further by showing the possible use of wearable sensor technology for information critical information systems, through the design and development of a proof-of-concept prototype.

Keywords: Wearables, sensors, design and development, smart clothing

1 Introduction

The topic of wearable computing and smart garments have been researched and developed for several decades (Mann, 1996), but has only in recent years become a popular research field. Gartner first introduced *Wearable User Interfaces* into their Hype Cycle for Emerging Technologies in 2013, two years after introducing *Internet of Things* (Figure 1). Since its introduction, it has stayed on the Peak of Inflated Expectations, but is showing a trend of moving into the Trough of Disillusionment. According to Gartner, when a technology transitions into the Trough of Disillusionment, it is expected to see an increase in failed experiments and implementations within the field, and a struggle to satisfy the early adopters of, and investors for the technology (Gartner, 2016). Because of this, it is important that research on this field focuses not only on simple prototypes and single-case studies, but also on how it can be integrated with existing business practices.

For this paper, we will use Sonderegger's (2013) definition of smart garments:

"*Smart garments are clothes containing technology such as sensors, processors, communication equipment, displays or input devices that are integrated into a textile-*

adfa, p. 1, 2016.

based garment structure and provide some additional functionality compared to the classical physical and socio-cultural functions of clothing.”

We also make a clear distinction between the term wearables and the term smart garments, as the term wearables also includes smart watches and other similar technologies that can be worn, but does not fill the requirements of a garment.

According to Karrer et al. (2011), current smart garment systems consist of DIY approaches, textile music controls and specialized systems for health and sports. It has also recently been embraced by the fashion industry, predominantly with use of LEDs, and other sources of light, that enhance the visual impact of the garment (Rossi, Cinaz, and Tröster 2011; Ashford 2014a; Ashford 2015; Cochran, Zeagler and McCall 2015). Several companies are working to make this technology more accessible for everyone, and Adafruit is a company one of these companies. They focus on both providing hardware and easy-to-use electronic components, but also on providing guidance and extensive learning for their users. Included in their product line is a set of sow able components, with custom pads made for use with conductive thread, headlined by their electronics platform named Flora (Adafruit 2016). Another very similar product is the Lilypad Arduino (Fig. 1), originally developed to be a kit for schoolchildren and adults to learn how to build and program their own wearable computers (Buechley, Eisenberg, and Catchen 2008), and is now a part of Arduino’s own product line (Arduino 2016).

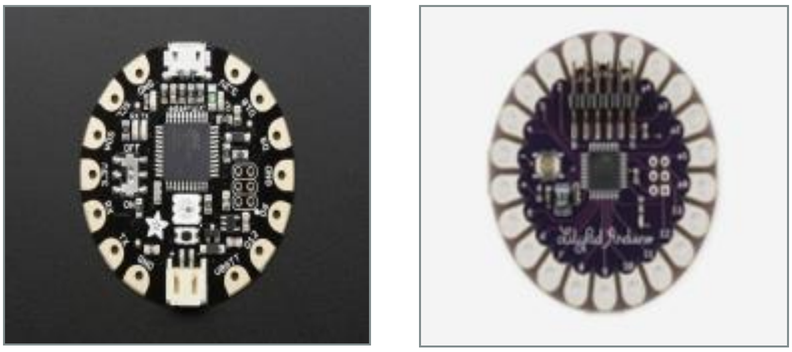

Figure 1 Arduino Processors

Although these examples far from indicate a widespread adoption of this technology, it does demonstrate the fact that the smart garment industry is not just catering those with existing knowledge about the technology, but also people competent in other areas, such as fashion. Because cooperating with the fashion industry is instrumental to developing successful smart garments (Jacob and Dumas 2014; Silina and Hadaddi 2015; Cochran, Zeagler, and McCall 2015), this trend of making wearable technology easy to use and develop may be instrumental to a successful, widespread adoption of smart garments.

According to Perera et al. (2014), most of the research done on IoT during the last two decades has been focused around prototypes, systems and solutions with a limited number of data sources. However, as the technology develops, a need to be context-aware and able to utilize a large number of sensors arises, and with this, the need to develop solutions which implement a strong core architecture, and is flexible and modular enough to be combined with other IoT solutions (Perera et al. 2014). One way of exploring how this would apply to the development of a smart garment, is to look at how we can connect the garment to other context sources, and how we can make a garment architecturally robust enough to be utilized by many different kinds of applications. In addition to this, the development of smart garments poses particular challenges tied to wearability, fashionability and durability (Karrer et al. 2011) not seen in many other technological solutions.

Our goal for this paper is to look at how both the architectural- and physical requirements of the garment can be met, in a way which is flexible and powerful enough to be context aware. Our method for exploring this will be to develop a prototype of a smart garment which is simple enough to be worn as a normal garment, but at the same time, architecturally sound enough to support being utilized by different applications and contexts. Because of this, the research question for this paper will be:

What considerations are needed when designing a smart garment suitable for a range of unknown applications?

To answer this, we will present a prototype of a smart garment in the form of a jacket containing both input, output and networking devices, and how this garment can be used with different contexts.

2 Background

To provide a robust solution, we have done a thorough literary search on similar projects and solutions. This includes topics relating both to placement and configuration of the hardware and the garment, as well as architecture and context management.

A reoccurring trend with smart garments is the development of products placed on the user's chest or arms (Davide et al. 2014; Karrer et al. 2011; Pailes-Friedman et al. 2014; Jacob and Dumas 2014; Koo 2014; Pailes-Friedman 2015; Mann 1996; Todi and Luyten 2014; Bian, Yao, and Hirsch 2011; Randell and Muller 2000). Several of these include research and testing which supports this being the ideal placement for smart garment technology as it is now (Pailes-Friedman et al. 2014; Karrer et al. 2011; Gemperle et al. 1998). From their user tests, Karrer et al. found that, for placement of an input device where the user pinches a piece of fabric, they found that the forearms, upper arms and area around the collar bone as most popular. The testing also revealed that the chest may not be suitable for interaction, both because it was seen as possibly socially unacceptable, and also because it may not be compatible with the use of, for instance, a low-cut top (Karrer et al. 2011). Because of this, a jacket with an open front has been chosen for the prototype for this project.

As previously mentioned, Karrer et al. (2011) highlight wearability, fashionability and durability as challenges when designing, engineering and manufacturing smart garments. To make sure we me9et the challenges tied to wearability, we will be following the set of design guidelines for wearability presented by Gemperle et al. (1998). The guidelines including the following listing, from simple to more complex: Placement (where on the body it should go); Form language (defining the shape); Weight (as its spread across the human body); Accessibility (physical access to the forms); Aesthetics (perceptual appropriateness); Long-term use (effects on the body and mind).

These guidelines have been used to dictate the design of the garment, and will be used as a benchmark to evaluate whether or not the solution meets the challenge of wearability. Regarding the challenge of fashionability, Karrer et al. (2011) suggest that the electronics in the garment, if possible, should be completely hidden. However, we would argue that fashion is about much more than just whether or not the electronics are visible, but also how the garment reflects the societal impact the garment has. In general, clothing can have two distinguished functions: the physical and socio-cultural function (Sonderegger 2013). Not only do clothes keep us protected from the elements, but it can also reflect the wearer's individual, sexual, cultural or religious characteristics and social status (Sonderegger 2013). When looking more specifically at wearables, the solutions can generally be divided into *responsive and emotive wearables* (Ashford 2014b). Responsive wearables are a term which describes a wearable technology that reacts to the user's social environment, or one which intercepts, processes and displays data from other devices and context sources (Ashford 2014b). Emotive wearables on the other hand are technologies which amplifies physiological data associated with non-verbal communication, reflecting, for instance, the user's emotions or mood (Ashford 2014b). This indicates that smart garments may use electronics not only to make a hidden computer, but also to open up new avenues for self-expression, being able to adapt itself to the needs and wants of the user continually. In some cases, it can even assist users who have problems expressing themselves due to mental conditions such as autism (Koo 2014).

Finally, regarding durability, Karrer et al. (2011) state that in order to truly function as a regular garment, the smart garment must be able to be stained, washed and dried repeatedly. According to Berglund et al. (2015), solutions utilizing conductive thread may be suitable for machine washing, however, it seemed that tumble-drying should be avoided. Although this test is quite limited in the materials tested, it does indicate that it would be possible to treat garments containing conductive thread and fabrics just as you would any other delicate garments. Using solder points on components is however more fragile to stoastic, high-intensitivity wear conditions (Berglund et al. 2015). Testing also indicates that using lines of conductive thread is more advantageous than conductive fabrics with woven conductive yarn, as the fabric is harder to isolate, and often enforces an orthogonal, constrained trace layout (Berglund et al. 2015). Their research also suggests that having many, short stitches may me more reliable than few and long ones.

The functions of the garment must also, naturally, be user-friendly and easy to use. In their paper, Holleis et al. (2008) test and evaluate input on smart garments in the form of capacitive touch. They conclude that, for project using similar input methods, four main aspects are important:

- Finding an input design which is compatible with a large array of people;
- Having the controls be easy to find;
- That it supports one-handed interaction;
- Ensures that the feedback from the action is immediate.

Usability also includes challenges such as connecting the garment to other devices, the different kinds of output devices it can use and what components the user has access to. Being able to connect the garment to other devices and the internet is essential to classifying the garment as smart, and essential to the success of the product (Gubbi, Buyya, and Marusic 2013; Henfridsson and Lindgren 2005). To ensure that the garment truly is user friendly, rigorous user testing is needed. To mitigate the halo-effect, an effect which indicates that users correlate the attractiveness of the product with its usability, it is necessary to do long-term testing, over several hours or days (Sonderegger 2013).

In the context of a garment not tied to a specific application, a scalable and robust architecture is a necessity. According to Perera et al., a modular architecture, with no single control point, is the best way to achieve this. They list 12 design principles they consider to be most important when designing the architecture of an Internet of Things device: Components and layering, scalability and extensibility, easy-to-use API, debugging mechanisms, automatic life cycle management, context model in-dependency, extended, rich and comprehensive modelling, multi-model reasoning, mobility support, sharing information, resource optimization and monitoring and detecting events

These are design principles on which the design of a possible application for the garment are based, and will be measured by.

3 Design and implementation

Based on the previously mentioned research by Karrer et al. (2011) and several others, we have chosen to use a jacket as the choice of garment for this prototype, in order to make the implementation of this application feasible and related to the cases (See Fig. 2).

Figure 2 Smart Garment

3.1 Garment

The garment itself is a blazer, made out of a fabric with little to no stretch. This is to ensure that the conductive thread used will not stretch and lose its connection during use (Fig. 3). The jacket also has an inner lining which allows access to the interior of the garment by just opening a few stitches in one seam. The garment contains an Adafruit Flora (Adafruit 2016), connected to a Bluetooth module (Adafruit 2016) that

Figure 3 Close-ups of the prototype

is placed directly beside the Flora. These two components do most of the logic handling in the garment, the Flora doing all the computational tasks, and the Bluetooth module securing the connection between the garment and other devices.

Bluetooth was chosen because of its compatibility with many different devices and easy connection and setup.

From the Flora, 4 lines of 3-ply conductive thread (Adafruit 2016) is sown into the lining of the garment, following the garment's natural seams to ensure maximum stability, ensuring that they won't budge around. Initial testing indicates that this connection is stable, but further user testing is needed to verify that this configuration is stable enough for use. The conductive thread runs down the right arm of the garment, connecting to the Lux light sensor (Adafruit 2016), and is further used to chain this sensor to the color sensor. Both of these sensors are located on the right forearm. Because of the chainable nature of the sensors, adding additional sensors poses little to no additional challenge.

The garment also contains two separate LED strips, one located on the exterior of the garment on the left upper arm, meant to be used for situations where you would want high visibility, and one located on the inside of the left wrist, giving a subtle lighting effect to notify the user. Because the LED strips used in this project do not include sowable pads, the strips had to be connected through wires soldered to pads on the strips, and on the Flora. For this a flexible, silicon coated wire has been chosen, and any areas where the solder or wire is exposed, is covered by shrink tubing to insulate it. The wires are drawn along the inside of the jacket, between the lining and the outer fabric layer. Because the LED strips can be chained in a similar fashion to the sensors, the 5V and GND connections have been chained from the high-visibility lights to the subtle lights. The data line to the subtle lights, however is drawn directly to the Flora, to make it more easy to address and program (Fig. 4). The testing done during implementation indicated that the jacket is still fully functional as a piece of clothing, and that the hardware does not contribute to any significant discomfort.

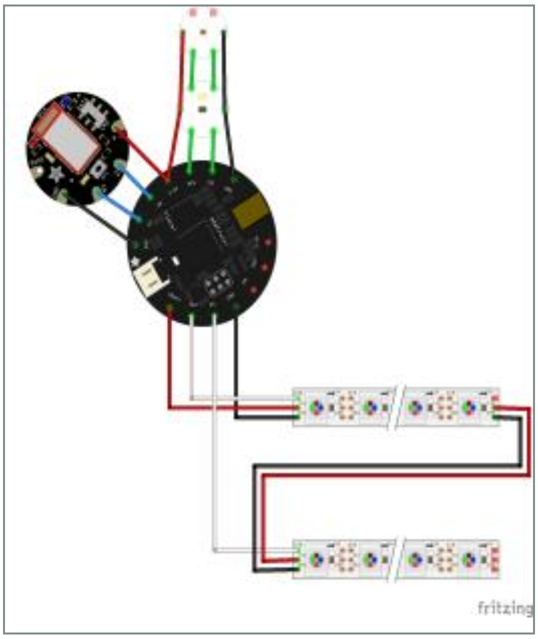

Figure 4 Wearable schematics

3.2 Application

The example application we have chosen for this project is one which demonstrates the combination of different contexts with the garment, and how all the components can be given different instructions according to the needs of the user's environment. The app is designed for use with conferences and similar indoor places where the user wants to locate points of interest. The following scenarios are given:

Scenario 1:

The user, Alice, is going to a large conference venue, and has a particular set of booths that she would like to visit and companies to speak to during the conference. All the businesses have their own stand at the conference, and the organizers of the event has fitted each stand with a beacon, and made an API tying each beacon to a specific business. This API is used in an application which Alice uses, and connects to the garment. She plots the businesses she's interested in, into the application.

Her friend, Johnny, is meeting her there. Unfortunately, he cannot find her in the crowd of people, so Alice activates her high-visibility lights, which she previously had set to light up with the same color as her top with the color sensor. She is now clearly distinguishable, and Johnny locates her. They both go into the conference.

The application registers when she enters the location, and when she goes near a point of interest, the LEDs at her wrist start shining dimly. As she walks nearer the stand, her wrist shines brighter, to help her find the right stand.

Scenario 2:
A fire breaks out in the cellar of the conference, causing the fire alarm to activate, and, because of damage to electrics, makes the lights of the location go out. When the fire alarm is triggered, the application goes into emergency mode, and the high visibility lights are turned on. Several other participants are also wearing the garment, and the LEDs of those closest to the emergency are brighter than others, using the location data from a battery-driven beacon. The garment has automatically adapted the brightness of the lights according the light of the dark room by using the light sensor, to ensure that the LEDs are clearly visible without being obtrusive. Using the brightest lights are a guide, she quickly finds her way out of the building and into safety.

These two scenarios demonstrate use of the same components used by two different contexts, the high visibility lights, being used both to make the user visible, and to guide the user to the nearest exit. It also demonstrates the combination of several different devices and context, by including both the beacon system and the fire alarm system.

3.3 Software Architecture

Based on the two previously mentioned scenarios, we have made a graphical model representing a preliminary software design architecture, using the guidelines presented by Perera et al. (2014) as a foundation (Fig. 5).

It shows a modular setup, where each service has a very limited and tightly defined role. From top to bottom, we first see development and debugging services, acting as a middle layer between the developer and the garment, providing a data model and services specifically modelled for development and debugging. Further we see the software on the garment itself just contains methods to read from and write to the components. Little to no data modelling is done on this layer, as the modelling may be context specific. The context acquisition for the garment itself is therefore based on responsibility, where acquisition happens through pull- and push methods (Perera et al. 2014). From there the data is sent to the user's device through Bluetooth, and the application on the device handles routing to the correct data modeler and combining the data from the garment with other contexts.

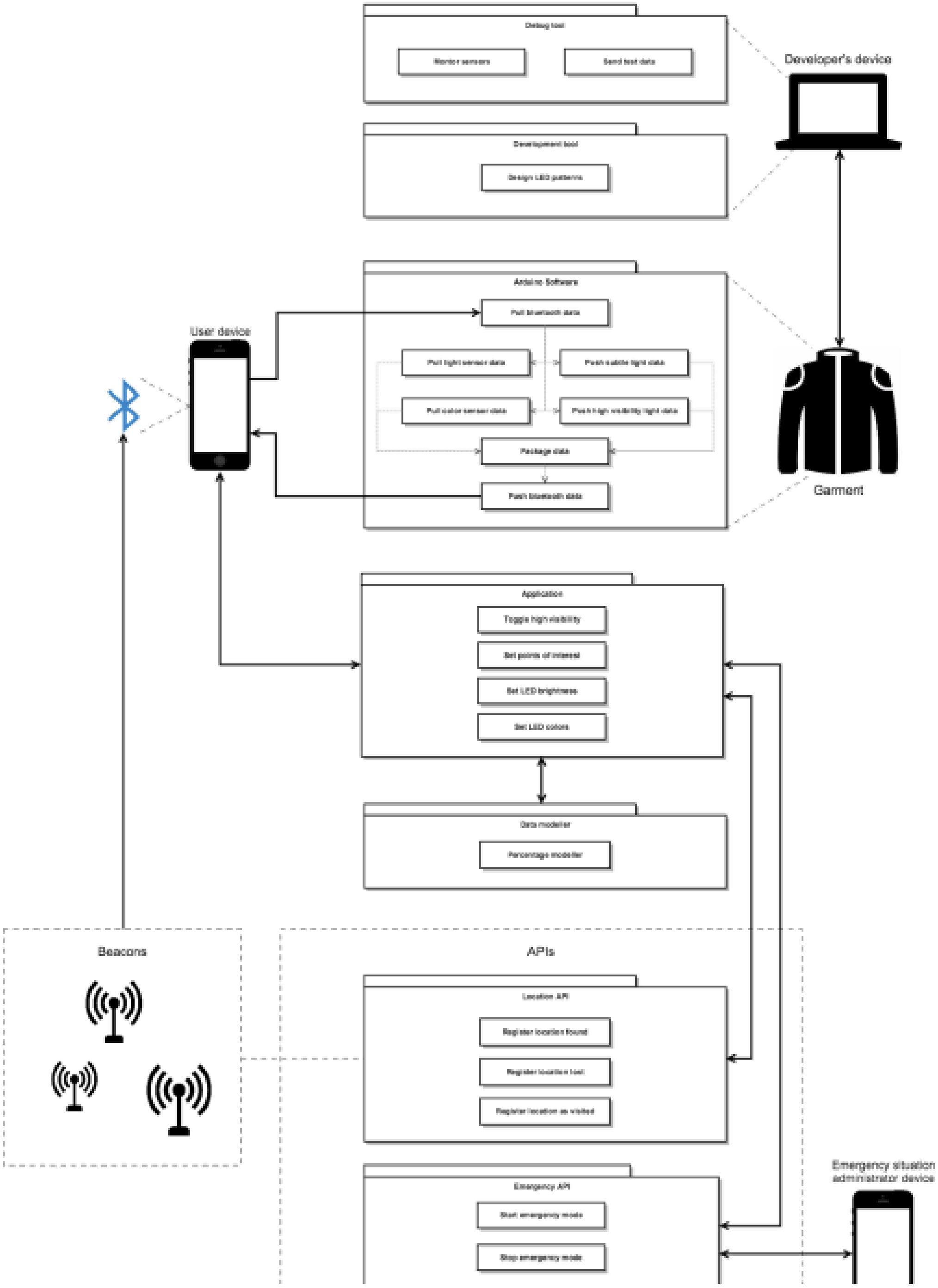

Figure 5 Software architecture

Conclusions and Future Work

This research highlights the novelty of wearable computing for information critical purposes. Through design, prototype development and architectural blueprints a novel approach for sensor integration in clothing is shown. The approach is low cost, feasible and solves real world challenges. Further work will include a large scale user test and evaluation to harvest data from the actual use of the garment. We will further pursue continuous development of wearable computing as an answer to ubiquitous computing and a full user test will enable rigorous testing of sensor based clothing for innovative user activities.

References

Adafruit, 2016a. About Us. Available at: https://www.adafruit.com/about [Accessed April 5, 2016].

Arduino, 2016. Lily Pad Arduino Main Board. Available at: https://www.arduino.cc/en/Main/ArduinoBoardLilyPad [Accessed April 1, 2016].

Ashford, R., 2014a. Baroesque Barometric Skirt. Proceedings of the 2014 ACM International Symposium on Wearable Computers: Adjunct Program, pp.9–14. Available at: http://doi.acm.org/10.1145/2641248.2641271.

Ashford, R., 2014b. Responsive and emotive wearables. Proceedings of the 2014 ACM International Symposium on Wearable Computers Adjunct Program - ISWC '14 Adjunct, pp.99–104. Available at: http://dl.acm.org/citation.cfm?doid=2641248.2642731.

Ashford, R., 2015. ThinkerBelle EEG amplifying dress. Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2015 ACM International Symposium on Wearable Computers - UbiComp '15, pp.607–612. Available at: http://dx.doi.org/10.1145/2800835.2801673\nhttp://dl.acm.org/citation.cfm?doid=2800835.2801673.

Berglund, M.E. et al., 2015. Surface-Mount Component Attachment for E-Textiles. In ISWC '15 Proceedings of the 2015 ACM International Symposium on Wearable Computers. pp. 65–66.

Berglund, M.E. et al., 2014. Washability of e-textile stretch sensors and sensor insulation. In Proceedings of the 2014 ACM International Symposium on Wearable Computers - ISWC '14. New York, New York, USA: ACM Press, pp. 127–128. Available at: http://dl.acm.org/citation.cfm?doid=2634317.2634326 [Accessed April 7, 2016].

Bian, L., Yao, L. & Hirsch, M., 2011. Queen's New Clothes. Proceedings of the 8th International Conference on Advances in Computer Entertainment Technology - ACE '11, p.1. Available at: http://dl.acm.org/citation.cfm?doid=2071423.2071531.

Buechley, L., Eisenberg, M. & Catchen, J., 2008. The LilyPad Arduino: Using computational textiles to investigate engagement, aesthetics, and diversity in computer science education. CHI '08 Proceedings of the twenty-sixth annual SIGCHI conference on Human factors in computing systems, pp.423–432. Available at: http://dl.acm.org/citation.cfm?id=1357123.

Cochran, Z., Zeagler, C. & McCall, S., 2015. Addressing Dresses: User Interface Allowing for Interdisciplinary Design and Calibration of LED Embedded Garments. In ISWC '15 Proceedings of the 2015 ACM International Symposium on Wearable Computers. pp. 61–64.

Davide, B. et al., 2014. Jackit: Power Generating Jacket. Proceedings of the 2014 ACM International Symposium on Wearable Computers: Adjunct Program, pp.27–32. Available at: http://doi.acm.org/10.1145/2641248.2641274.

Gemperle, F. et al., 1998. Design for wearability. Digest of Papers. Second International Symposium on Wearable Computers (Cat. No.98EX215), pp.116–122. Available at: http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=729537.

Gubbi, J., Buyya, R. & Marusic, S., 2013. Internet of Things (IoT): A Vision, Architectural Elements, and Future Directions. Future Generation Computer Systems, 29(7), pp.1645–1660.

Henfridsson, O. & Lindgren, R., 2005. Multi-contextuality in ubiquitous computing: Investigating the car case through action research. Information and Organization, 15(2), pp.95–124.

Holleis, P. et al., 2008. Evaluating capacitive touch input on clothes. Proceedings of the 10th international conference on Human computer interaction with mobile devices and services - MobileHCI '08, p.81. Available at: http://portal.acm.org/citation.cfm?doid=1409240.1409250.

Jacob, C. & Dumas, B., 2014. Designing for intimacy: How fashion design can address privacy issues in wearable computing. Proceedings of the 2014 ACM International Symposium on Wearable Computers, pp.185–192. Available at: http://dl.acm.org/citation.cfm?id=2641353.

Karrer, T. et al., 2011. Pinstripe: Eyes-free Continuous Input on Interactive Clothing. Proceedings of the 2011 annual conference on Human factors in computing systems - CHI '11, pp.1313–1322. Available at: http://dl.acm.org/citation.cfm?doid=1978942.1979137.

Koo, H., 2014. "TellMe": therapeutic clothing for children with autism spectrum disorder (ASD) in daily life. Proceedings of the 2014 ACM International …, pp.55–58. Available at: http://dl.acm.org/citation.cfm?id=2641278.

Mann, S., 1996. Smart clothing: the shift to wearable computing. Communications of the ACM, 39(8), pp.23–24.

Pailes-Friedman, R., 2015. BioWear: A Kinetic Accessory that Communicates Emotions Through Wearable Technology. UbiComp '15 / ISWC '15 - Adjunct Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing and the 2015 ACM International Symposium on Wearable Computers, pp.627–633.

Pailes-Friedman, R. et al., 2014. Electronic-Textile System for the Evaluation of Wearable Technology. ISWC '14 Adjunct, pp.201–207.

Perera, C. et al., 2014. Context aware computing for the internet of things: A survey. IEEE Communications Surveys and Tutorials, 16(1), pp.414–454.

Randell, C. & Muller, H., 2000. The Shopping jacket: Wearable computing for the consumer. Personal and Ubiquitous Computing, 4(4), pp.241–244.

Rossi, M., Cinaz, B. & Tröster, G., 2011. Ready-to-live: wearable computing meets fashion. Proceedings of the 13th international conference on Ubiquitous computing, pp.609–610. Available at: http://doi.acm.org/10.1145/2030112.2030238.

Silina, Y. & Haddadi, H., 2015. " New Directions in Jewelry ": a Close Look at Emerging Trends & Developments in Jewelry - like Wearable Devices. In ISWC '15 Proceedings of the 2015 ACM International Symposium on Wearable Computers. pp. 49–56. Available at: http://dl.acm.org/citation.cfm?id=2808410.

Sonderegger, A., 2013. Smart garments -- the issue of usability and aesthetics. Proceedings of the 2013 ACM conference on Pervasive and ubiquitous computing adjunct publication - UbiComp '13 Adjunct, pp.385–392. Available at: http://www.scopus.com/inward/record.url?eid=2-s2.0-84885205848&partnerID=tZOtx3y1.

Todi, K. & Luyten, K., 2014. Suit up!: Enabling eyes-free interactions on jacket buttons. Conference on Human Factors in Computing Systems - Proceedings, pp.1549–1554. Available at: http://www.scopus.com/inward/record.url?eid=2-s2.0-84900550993&partnerID=40&md5=fb4fc9a9e5b3fc19b8cc4d9cba3b2f9a.