This is a pre-copyedited version of a contribution published in Artificial Intelligence on Fashion and Textiles, Advances in intelligent Systems and Computing 849, W. K. Wong (ed.) published by Springer. The definitive authenticated version is available online via https://doi.org/10.1007/978-3-319-99695-0_16

Challenges in Knitted E-textiles

Amy Chen[1], Jeanne Tan[1], Xiaoming Tao[1], Philip Henry[2] and Ziqian Bai [1]

[1]Institute of Textiles and clothing, Hong Kong Polytechnic University, Hong Kong
[2]School of Design, University of Leeds, Leeds, United Kingdom
amy.f.chen@connect.polyu.hk

Abstract. This paper considers the progress made in E-textiles within knitted textiles and discusses what 'Project Jacquard' and the debut of the woven Levi's Commuter X Jacquard by Google jacket helps reveal about the relationship between E-textiles and textiles manufacturing. The paper considers research conducted within the fields of Art, Design and Technology, along with materials with interesting and novel properties that have been integrated into knitted textiles by practitioners and researchers. Such materials can embellish or enhance knitted fabric, from creating additional visual interest to practical functions. However, due to the physical properties of these types of materials, not all materials can be knitted into the fabric with ease; the optimal machine settings and techniques must be determined. Adapting to the physical characteristics of these innovative materials is a logical design requirement of the prototype development process but when we look to adopt the same principles as 'Project Jacquard'; manufacturing knitted E-textiles to scale, the challenges of the material/machinery relationship become more of an issue. This raises the question as to whether it is better to develop the material for better textiles integration, or to optimize the production process to suit the material.

Keywords: E-textiles, Photonic Textiles, Polymeric Optical Fibers, Knitted Fabric, Electronics, Conductive yarn

1 Introduction

E-textiles has been steadily making its way into mainstream garments. Earlier E-textiles garments, such as the Galaxy dress by CuteCircuit [1] used hand embroidered circuity, while recently 'The Marlene Project' [2] used the technique of e-broidery® to integrate lighting into the garment. Now, in a step towards everyday apparel, Google's Project Jacquard and Levi's have developed the Commuter X Jacquard jacket, which incorporates a woven ‘gesture-sensitive’ fabric that provides the wearer with the opportunity to control their mobile phone through their jacket [3].

This practical functionality exemplifies E-textiles being incorporated into a fashionable garment but do not fully reflect the wider innovation in this area. Academic research shows a greater diversity in E-textiles, with the development of sensors, actuators and power sources. A number of different textiles manufacturing techniques have been utilized to create E-textiles, such as handcraft techniques like crochet and felting[4], fabric printing [5] and dyeing [6], knitting [7], as well as weaving[8] and embroidery.

While advanced knitting technologies are now being used by fashion and sports brands, i.e. seamlessly knitted garments and footwear by Uniqlo and Nike respectively, knitted E-textiles is not present in more mainstream garments, despite the progressive academic research in this area. Current literature presents the challenges and solution for knitted E-textiles at a small scale, consequently, there is a limit to the applicability of those design principles to larger scale production. Therefore, it is useful to analyze Google’s ‘Project Jacquard’, as it provides an insightful case study for scalable E-textiles integration.

2 Knitted E-textiles

Innovative materials can be more easily integrated into fabric when their properties are very similar to that of conventional yarns. Conductive yarns demonstrate this principle. In contrast, Polymeric Optical Fibers (POF) have very different physical properties to conventional yarn. They are more rigid and structurally different to yarns. While it might be assumed that conductive yarn can be knitted into a garment with ease, there are still issues that need to be considered during the design process.

2.1 Polymeric Optical Fibers

Polymeric optical fibers (POF) can be used for sensing and illumination purposes. Fiber Bragg grating (FBG) is one of the techniques that is used to create POF sensors, and existing reviews on the subject have discussed its use as a strain, temperature or humidity sensor [9]. FBG works in that the technique changes the refractive index in the fiber’s core. Optical signals are transmitted through the fiber and reflected by the FBG. When there is a change in conditions i.e. temperature change, this affects the wavelength of the light that is reflected. The POF acts as a sensor by measuring the change in the reflected light.

POF are not suited to being knitted into a fabric, as the tight bends of the knitted structure can cause excessive damage, preventing light from traveling along the full length of the fiber. On the other hand, a certain amount of damage to the fiber is necessary for illumination via the lateral side of the fiber, and further processes, like laser engraving, can be used to determine the light emission levels [10]. To overcome the challenges of knitting with POF, Inlay has been used to incorporate POF into knitted fabric. The POF is held in place by the knitted loops, rather than being knitted into the fabric and this is accomplished through either hand or machine manipulation. By using Inlay, a range of fiber diameters can be used, with the cited examples using POF from 0.25mm to 0.75mm.

Inlaying can place some restrictions on the design of the fabric and garment. The knit POF samples produced as part of CraftTech [11] show that patterns can be created by manipulating the knit structure to reveal select areas of POF. Nevertheless, the POF is still integrated horizontally, which impacts the drape of the fabric, and subsequently the silhouette of the garment [12]. Yet, the rigidity of POF can be used to its advantage, as seen in the sculptural knitted art pieces by Bettina Blomsedt [13]. While POF requires the additional step of attaching the POF to the light source, one benefit of this material is that a large section of fabric can be illuminated by using one light emitting diode.

2.2 Conductive yarn

Compared to POF textiles, there are a greater number of examples of E-textiles using conductive yarns. This is potentially due to conductive yarns being easier to integrate, and the wide variety of conductive fibers and yarn available. Conductive yarns utilize the knitted structure to perform sensing and actuating functions. Stretch sensors functionality uses the change in resistance caused by stretch of the fabric, while the stroke sensing fabric detects the action by behaving in the same way as a switch in an electrical circuit [4]. Heated fabric can also be produced using conductive yarn [14], which dissipates the electrical power through the conductive yarn as heat. Spacer fabric has been adopted in the development of energy harvesting textiles. The energy harvesting fabric generates electricity as a result of pressure applied upon the fabric, which consists of electro-spun piezoelectric yarn knitted as spacer yarn, with conductive and non-conductive yarn used for the fabric faces [15].

Conductive yarn can be knitted into a range of fabric structures, given that they are the appropriate weight for the machine gauge. However, the development in conductive yarns focuses on its technical applications as opposed to the look and feel. Conductive yarns are predominantly grey or silver, and this can impact on the garment design decisions. For examples, in the heated garments produced by Chu Yin Ting, "the conductive paths were designed to match with the parallel vertical stripes … so that the paths become part of the pattern design" [16]. For spacer fabric, which has a distinctive draping quality, it is necessary to consider the impact of its placement on the garment and the effect on the garment form. While conductive yarns have overcome the technical difficulties, it presents some challenges when we look at integrating it into the design of a garment.

3 Google Jacquard: E-textiles at scale

A key aim of the Project Jacquard was to develop solutions to "enable employing invisible ubiquitous interactivity at scale" [17]. Scalability is important as E-textiles moves beyond the realms of occasion wear and into everyday wear. Nevertheless, it is difficult to pursue economies of scale without the demand for the product [18].

3.1 Textiles Industry requirements

During the development process of Project Jacquard, the same observation was made regarding the aesthetic limitations of conductive yarn. The solution that was developed was a conductive yarn consisting of conventional yarn braided around copper core, designed to have a “natural look and feel” [17]. The braided element of the yarn allows for a greater variety of colors and textures. The yarn has been successful used in industrial looms. Based on this, it suggests that the Jacquard yarn could work within a knitted structure, given that it has similar physical properties to conventional yarn.

Project Jacquard developed gesture sensitive fabric and assembled into a garment through conventional cut and sew garment construction in collaboration with fashion designers. Cut & Sew is a knitwear construction technique is comparable woven garment construction, but there are other garment construction methods. Fully Fashioned consists of knitting garment pieces to shape before assembly, and in Whole Garment/Seamless knitting, the whole garment is knitted on the machine [19]. There are advantages and disadvantages to each method. Whole Garment knitting produce less waste, saving on material cost, and the seamlessness of the garment reduces labor cost while being more comfortable. However, this newer technology comes at a higher cost. In contrast, Cut & Sew is the most common production method, and does not require computerized knitting machines. As the fabric is cut into shape, there is waste, and further labor costs for garment assembly. The estimates on cost are further complicated by the fact that the cost varies depending on the style of the garment [20]. The relationship between knitted E-textiles and construction technique requires some investigation to strike a balance between cost-effectiveness and the envisioned end-product.

3.2 Connecting electronics to textiles

Electronics and textiles have different connection methods, with soldering for electronics and sewing for fabrics. Processes currently being used in commercial E-textiles include computerized embroidery and pre-made textiles cables [21]. Hand processes have been used in small scale work [22]. Project Jacquard took that approach initially but it was considered “laborious and error-prone”[17]. Optimization is necessary for scalable manufacturing. For Project Jacquard, the connection process was resolved through 3D weaving. The fabric is woven “as a two-layer textile, where the conductive (red) yarn forms a localized square conductive area in the top layer, then passes through the fabric to the bottom layer, where it floats. There, the yarns are free from the textiles and can be addressed individually” [17]. The Jacquard yarns are then connected using traditional soldering processes. Creating floats is possible in knitted fabric, as seen in Fairisle knitted fabric. However, woven fabrics can produce floats horizontally and vertically, while knitted fabric only produces horizontal floats, which may be less versatile. Another design element that could be taken forward is the use of snaps for removable electronics, as seen in the Google & Levi’s jacket, the garments by Chu Yin Ting, and the textiles cables by Interactivewear [21].

A potential issue for knitted fabric is its extensibility. The weight of the electronics could cause unwanted stretch. This is not a problem for the Google & Levi's Jacket, which uses denim but could pose a problem for a ribbed knit fabric. Textiles cabling may not be suited to some knitted fabrics if they do not possess the same level of extensibility, or if the garment is thin, making the cabling visible.

4 Further considerations

The lessons learned from Project Jacquard can be transferred into knitted E-textile using conductive yarns, as many of the issues raised within Project Jacquard can be found in knitted conductive fabrics. Due the differences in both material and technique, the same cannot be said for POF. Jacquard yarn was designed to fit into the industrial weaving process and used existing weaving techniques to overcome connectivity issues. For POF, the manufacture process has been adjusted to suit the material's challenging physical properties. Even though POF is difficult to knit, it has been successfully integrated into knitted fabric using an Inlay capable computerized knitting machine, showing that there is potential for scalable production. On the other hand, the attachment processes for conductive yarn is also not directly transferable to POF, as POF carries light rather than electricity, and it cannot be heated to a high temperature [23]. At present, the fibers are bundled and attached to the light emitting diode by hand [10], reminiscent of Project Jacquard's hand process. Key questions for further POF textiles development are whether it is better to develop the material for better textiles integration, or to optimize the production process to suit the material. By redeveloping the material to improve its compatibility with existing knitting technologies, it may be more easily adopted as manufacturers, in their existing production setup, rather than them having to invest in new knitting equipment. With that being said, manufacturing E-textiles garments is not solely the matter of producing E-textiles fabric. As investment is required to process other elements of the garment, such as the electronic connections, it can be argued that investment in new technology is inevitable. With the knitting industry being so diverse in it production technologies and techniques, improving the scalability of knitted E-textiles may require a multifaceted approach.

5 References

1. Cutecircuit (2009) The Galaxy Dress. http://cutecircuit.com/collections/the-galaxy-dress/. Accessed 27/11/16

2. Elektrocouture (2017) The Marlene Project - ElektroCouture | Bespoke Elektronic Fashion Technologies. Elektrocouture. https://elektrocouture.com/the-marlene-project/. Accessed 14/9/17

3. Levi's (2018) Levi's® Commuter™ Trucker Jacket with Jacquard™ by Google. Levi's®. http://www.levi.com/US/en_US/womens-clothing-jackets-vests/p/287720000.

4. Perner-Wilson H, Buechley L, Satomi M (2011) Handcrafting textile interfaces from a kit-of-no-parts. Paper presented at the Proceedings of the fifth international conference on Tangible, embedded, and embodied interaction, Funchal, Portugal,

5. Karim N, Afroj S, Malandraki A, Butterworth S, Beach C, Rigout M, Novoselov KS, Casson AJ, Yeates SG (2017) All inkjet-printed graphene-based conductive patterns for wearable e-textile applications. J Mater Chem C 5 (44):11640-11648. doi:10.1039/c7tc03669h

6. Fugetsu B, Sano E, Yu H, Mori K, Tanaka T (2010) Graphene oxide as dyestuffs for the creation of electrically conductive fabrics. Carbon 48 (12):3340-3345. doi:https://doi.org/10.1016/j.carbon.2010.05.016

7. Wang J, Long H, Soltanian S, Servati P, Ko F (2014) Electromechanical properties of knitted wearable sensors: part 1 – theory. Textile Research Journal 84 (1):3-15. doi:10.1177/0040517513487789

8. SubTela S (2007) White Wall Hanging. http://subtela.hexagram.ca/Pages/White%20Wall%20Hanging.html.

9. Zeng W (2015) Polymer Optical Fiber for Smart Textiles. In: Tao X (ed) Handbook of Smart Textiles. Springer Singapore, Singapore, pp 109-125. doi:10.1007/978-981-4451-45-1_23

10. Tan J (2015) Photonic Fabrics for Fashion and Interior. In: Tao X (ed) Handbook of Smart Textiles. Springer Singapore, Singapore, pp 1005-1033. doi:10.1007/978-981-4451-45-1_29

11. Tan J, Toomey A (2018) CraftTech: Hybrid Frameworks for Smart Photonic Materials. Royal College of Art, UK

12. Chen A (2017) Literature Review and Research Methodology. Creating an Effective E-textiles Toolkit for Fashion Design. Manchester Metropolitan Univerisity,

13. Blomstedt B (2017) LUX: Exploring interactive knitted textiles through light and touch. University of Boras,

14. Mbise E, Dias T, Hurley W (2015) 6 - Design and manufacture of heated textiles. In: Electronic Textiles. Woodhead Publishing, Oxford, pp 117-132. doi:https://doi.org/10.1016/B978-0-08-100201-8.00007-2

15. Soin N, Shah TH, Anand SC, Geng J, Pornwannachai W, Mandal P, Reid D, Sharma S, Hadimani RL, Bayramol DV, Siores E (2014) Novel 3-D spacer all fibre piezoelectric textiles for energy harvesting applications. Energy Environ Sci 7 (5):1670-1679. doi:10.1039/c3ee43987a

16. Chui YT (2017) Creation of wearable electronic clothing addressing end-user needs. Hong Kong : Institute of Textiles and Clothing, The Hong Kong Polytechnic University, Hong Kong

17. Poupyrev I, Gong N-W, Fukuhara S, Karagozler ME, Schwesig C, Robinson KE (2016) Project Jacquard: Interactive Digital Textiles at Scale. Paper presented at the Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems, San Jose, California, USA,

18. Röpert A (2017) Smart Textiles – How to Enter the Market. Berlin

19. Power J (2008) 9 - Developments in apparel knitting technology A2 - Fairhurst, Catherine. In: Advances in Apparel Production. Woodhead Publishing, pp 178-196. doi:https://doi.org/10.1533/9781845694463.2.178

20. StitchWorld (2010) Flat Knit Production A Comparative Analysis. Stitch World

21. Mecnika V, Scheulen K, Anderson CF, Hörr M, Breckenfelder C (2015) 7 - Joining technologies for electronic textiles A2 - Dias, Tilak. In: Electronic Textiles. Woodhead Publishing, Oxford, pp 133-153. doi:https://doi.org/10.1016/B978-0-08-100201-8.00008-4

22. Peppler K, Sharpe L, Glosson D (2013) E-textiles and the New Fundamentals of Fine Art. In: Buechley L, Peppler K, Eisenberg M, Kafai Y (eds) Textile messages : dispatches from the world of e-textiles and education. Peter Lang Publishing, Inc, New York,
23. Bai Z (2015) Innovative photonic textiles : the design, investigation and development of polymeric photonic fiber integrated textiles for interior furnishings. Hong Kong : Institute of Textiles and Clothing, The Hong Kong Polytechnic University, Hong Kong