Chapter 9
Reversible Contacting for Smart Textiles

Andreas Mehmann, Matija Varga and Gerhard Tröster

Abstract Smart textiles include integrated sensors and actuators, which are connected to electronics to read or control. Various ways of connecting electronics to textiles exist. In this chapter, we will give an overview of these electronics-to-textile connector prototypes. While the different connection types have advantages and disadvantages, there is a trade-off between the size and the number of connections. The electronics can be fabricated with pitches of 0.2 mm, but the textile part has lower limits on the size given by the textile fabrication processes such as stitching and weaving. The connection can be fixed, which implies better reliability and less rigid components, or removable, which allows the separation of textile and electronics for charging or washing.

9.1 Introduction

The textile sensors and actuators and their applications increase the requirements on data transmission and processing in smart textiles. The performance of processing units, such as mobile phones, has increased over recent years. Complex data analysis of sensor signals can be performed on smartphones. Meanwhile, the link from the textile sensors and actuators to the processing units has not received much attention. The processing power of smartphones also offers the possibility for applications combining different signals with simultaneous signal acquisition (see Chap. 14). Acquiring data signals from different sensors in the textile increases the number of necessary connections. Therefore, we investigate different electronics-to-textile connectors for smart textile applications.

A. Mehmann (✉) · M. Varga · G. Tröster
ETH Zürich, Zürich, Switzerland
e-mail: andreas.mehmann@ife.ee.ethz.ch

M. Varga
e-mail: matija.varga@ife.ee.ethz.ch

G. Tröster
e-mail: troester@ife.ee.ethz.ch

S. Schneegass and O. Amft (eds.), *Smart Textiles*,
Human–Computer Interaction Series, DOI 10.1007/978-3-319-50124-6_9

The connectors are grouped into fixed and removable connections. A fixed connection cannot be disconnected without breaking the connector. A removable connection can be repeatedly disconnected and reconnected without impairing the mechanical stability of the connection. With removable connections in smart textiles, the electronic processing device can be separated from the garment. The garment can then be washed, while the electronic device is being charged.

In the following sections, different types of connections will be described. First, general requirements will be listed. Then, the different connection types will be investigated with respect to the aforementioned requirements.

9.2 Requirements for Smart Textile Connectors

The main goal of any electrical connector is to provide low ohmic and capacitive resistance and reliable electrical connection under various application scenarios. In this section, we highlight the challenges that are particularly important when choosing or designing electronics-to-textile connectors.

As mentioned before, the electrical connection should be maintained under mechanical stress. The application will determine the stress to be expected. At the same time, the connection should be easy to use, i.e. simple connecting and disconnecting for removable connectors.

Altering the shape and feel of a garment affects the wearer's comfort. Therefore, the size of the connector should be as small as possible. However, reducing the size of the connector is limited by the number of connections and the maximum density of connections. The maximum density of connections is higher in electronics than in the textile due to manufacturing processes and cumbersome alignment by the user. To ensure comfortable wear of the garment, rigid parts in the garment should be small or avoided. Also, the transition from textile to rigid parts is prone to break.

Since many steps in smart textile fabrication cannot be done by standard garment manufacturing processes, the fabrication of smart textiles is expensive and smart textiles have not yet been deployed as much as their functionality might suggest. Therefore, materials and processes from the textile industry are favoured.

9.3 Fixed Connections

Fixed connections cannot be disconnected without irreversibly breaking the connection. In this section, we describe thermal joining, mechanical fastening and adhesives used to connect electronics to textiles.

9.3.1 Thermal Joining

Under thermal joining, we subsume processes where materials are joined by the application of heat. The heat melts materials, which solidify and form bonds when cooled. The temperature to melt the material can damage the surrounding fabric. There are two main categories of thermal joining: welding and soldering.

Welding is a process where materials are joined by melting them at the joint. After the mixing of melted materials, they solidify when cooling down and thus form a bond. In the semiconductor industry, it is used for wire bonding. Copper, gold and silver melt at around 1000 °C, but localised pressure can reduce the temperature necessary to melt the metals to around 300 °C. The combination of pressure and heat for welding is called thermocompression bonding. With ultrasonic vibrations, the necessary temperature can be reduced to room temperature. In integrated circuits, wire connections are done with a combination of ultrasonic bonding and thermocompression at around 100 °C. This process is called thermosonic bonding [1].

Welding is also applied in garment fabrication [2]. It is usually referred to as thermal bonding [3]. A process for joining polyamides similar to thermosonic bonding is described by Potente et al. [4] under the name friction bonding. This process uses a lower frequency than the ultrasonic bonding, namely 240 Hz. Friction can also be generated by mechanical vibrations at ultrasonic frequencies of 20 to 40 kHz [5]. The advantage of the friction bonding compared to the thermal bonding is that the heat is generated directly at the joint. Localised heating reduces the risk of burning the surrounding fabric.

While the process of welding is well known, parameters such as material, pressure, energy and time often have to be determined empirically. Slight changes can effect the stability of the welds, and the parameters have to be re-evaluated. Also, special machinery is needed for this process.

In soldering, an additional material—called solder—bonds the substrate materials. The solder has a lower melting point than the substrate materials. By heating, the solder melts and through a wetting process attaches to the materials, before the heat is removed and the solder solidifies [6]. In this process, only the solder melts, and the other materials do not change their state of matter. However, in the case of metals, the substrate metal diffuses into the solder to form an intermetallic compound [7].

In the electronics industry, soldering is used to contact chips to circuit boards. The materials utilised in circuit boards are usually copper with gold and nickel coatings. All these materials have melting points above 1000 °C. Solder can be an alloy made from tin and lead, but due to its toxicity, the lead has been replaced by other metals.

Soldering is done at above 200 °C, although low-temperature solder with melting points as low as 50 °C exists [8]. For example, the Loctite Multicore 97SC 400 by Henkel consists of 96.5% tin, 3% silver and 0.5% copper. The solder alloy has a melting point of 217 °C [9]. MG Chemicals claim an electrical resistivity of 13×10^{-8} Ωm for the same alloy [10]. An example of a low-temperature solder is tin–indium alloy with 52% indium. It has a melting temperature of 120 °C and an electrical resistivity of 14.7×10^{-8} Ωm [11]. In comparison, the resistivity of copper is 1.7×10^{-8} Ωm.

9.3.2 Mechanical Fastening

In mechanical fastening, two objects are held together by a supporting structure that holds the objects in place. Examples of supporting structures are rivets, clamps, screws, etc. We also include binding or stitching in this category. Additionally, lamination, where a polymer is glued or welded onto the fabric fixing the underlying threads can be viewed as a kind of mechanical fastening.

9.3.3 Adhesive

Three categories of adhesives exist [12]. In one, hardening is achieved by cooling the adhesive. In the second, the bonding is achieved by a chemical reaction. The reaction is induced either by the mixing of two components, by the deprivation of oxygen or by the reaction with water. In the third category, the adhesive is cured by the removal of a carrier or solvent.

In textiles, the most commonly utilised adhesives to bind synthetic fibres are polymers, where the carrier is water, which is evaporated to bond [2]. Conductive adhesives contain a conducting material, usually graphite or silver. For example, silver epoxy is applied in chip bonding. Compared to soldering, the epoxy needs lower temperatures to cure, which is advantageous if the textile material is sensitive to heat. However, resistivity is higher compared to solder, and the epoxy is more brittle. For example, Epo-Tek® H20E, a two-component silver epoxy by Epoxy Technology, has a curing time of one hour at 150 °C. The electrical resistivity is 400×10^{-8} Ω m (c.f., 13×10^{-8} Ωm for 96.5Sn-3.0Ag-0.5Cu solder).

A method with non-conductive adhesives to bond circuit boards to textile has been proposed by Linz et al. [13]. The adhesive covering the textile is pressed aside by pressing the contact pads of the circuit board onto the conductive threads in the textile. After curing, the adhesive holds the circuit board in place to ensure contact between the pads and the threads.

9.4 Removable Connections

In this section, we give an overview of removable electronics-to-textile connections, namely hook and loop, snap fasteners, plug connectors, magnetic connections, and conductive zippers.

Fig. 9.1 Conductive hook and loop with silver coating. Image courtesy of adafruit.com

9.4.1 Hook and Loop

Hook and loop, commonly known under the trademark Velcro®, is a fastener that comprises hooks on one side of the connector, which hook into the loops on the other side of the connector. Hooks and loops are usually made of nylon and polyester. They are employed in the garment industry as replacements for zips, laces or buttons [14].

Conductive hook and loop fasteners are commercially available. For example, adafruit.com offers conductive hook and loop tape with advertised life cycles of 5000 openings and closings, and sheet resistance below $2\,\Omega/\Box$ [15]. Manufacturing includes coating with conductive material such as silver. Conductive hook and loop fasteners have been patented since the 1980s. They are applied for electrostatic shielding and for electrical contacting in smart textiles. Examples of applications in smart textiles are interconnecting blocks of e-textiles [16] or connecting textile antennas [17]. Seager et al. [17] investigated the frequency dependence of the conductivity and found that after electroplating, the insertion loss of a 4-mm-long hook and loop transmission line is less than 1 dB up to 2 GHz (Fig. 9.1).

9.4.2 Snap Fasteners

Snap fasteners are utilised in garment manufacturing. The snap fasteners are attached to a fabric by riveting or sewing. When coated with conductive materials, snap fasteners can act as electrical connectors in smart textiles. Conductive threads are connected to the conductive snappers by using a fixed connection method described in Sect. 9.3, such as thermal joining, mechanical fastening or adhesives.

An advantage of snap fasteners is that they are easy to disconnect. Snap fasteners are around 1 cm in diameter. For example, Prym provides sew-on snap fasteners ranging from 6 to 11 mm in diameter [18]. Conductive snap fasteners have been

Fig. 9.2 Snap fasteners with female part on leather and male part on a PCB. Image courtesy of Linz et al. at Frauenhofer Institute [20]

used for prototypes of smart textiles. Examples can be found in the work of Lehn et al. [19], Linz et al. [20], Ngai et al. [21] and Post et al. [22]. Commercial versions of circuit boards with a microcontroller and snap fasteners are available [23] (Fig. 9.2).

9.4.3 Plug Connectors

There are a number of shapes and forms of plug connectors, each specific to a certain application. A few examples of rigid plug connectors in textiles are given here. Ohmatex advertises a washable textile connector [24] with six connection points on an area of a few square centimetres. Wilson developed a buckle-type connector [25] with five pins. The buckle size is 11.4 cm $\times$ 4.2 cm. In [26], a flexible flat cable connector was clamped to a ribbon with conductive threads. The connector has four pins and is 1.5 cm wide and 2.7 cm long, as shown in Fig. 9.3.

9.4.4 Magnetic Connections

Magnetic connectors are employed in the electronics industry, since they can be easily attached and detached. An example is the MagSafe power connector in Apples MacBook Air and MacBook Pro [27]. Magnetic power connectors were introduced as breakaway electric cords for deep fryers and hot pots [28]. The magnetic connector disconnects when the cable is pulled. This prevents the deep fryers from falling over and spilling hot oil, which can injure people standing close.

Scheulen et al. [29] used neodymium magnets for contacts in smart textiles. The electrical contact resistance between two magnets was found to be less than 0.01 Ω. The magnets were glued to the textile using conductive epoxy adhesive in parallel

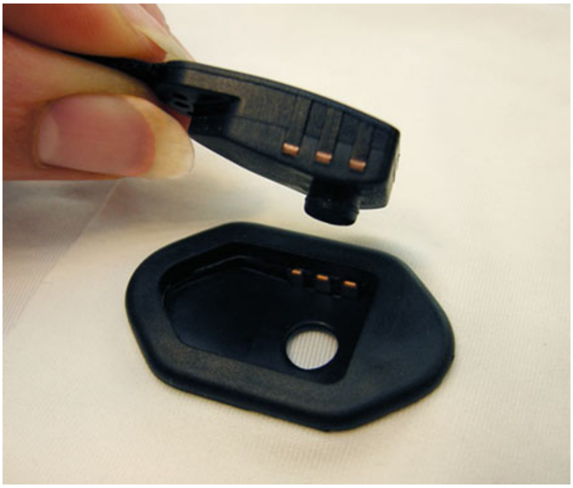

Fig. 9.3 Plug connector with female part integrated into textile. Image courtesy of Ohmatex [24]

with a non-conductive adhesive to ensure mechanical strength of the joint. The electrical resistance of the adhesive joint between the magnets and the silver-coated textile is less than 1 Ω for gold-coated magnets. The size of the magnet was about 5 mm squared.

Righetti et al. [30] developed a modular I2 C-based wearable architecture. The garment provides a bus made of four litz wires. At different positions, modules can be attached to the bus via magnetic connectors. The modules are 0.4-mm-thick flexible circuit boards. The magnets were glued to the circuit board with conductive silver epoxy. Master modules are responsible for initialising the slaves and centralising the data, while different slave modules either store data or include vibration motors and accelerometers, as shown in (Fig. 9.4).

Fig. 9.4 Magnetic connectors for I2C printed circuit board. © 2010 IEEE. Reprinted with permission from [30]

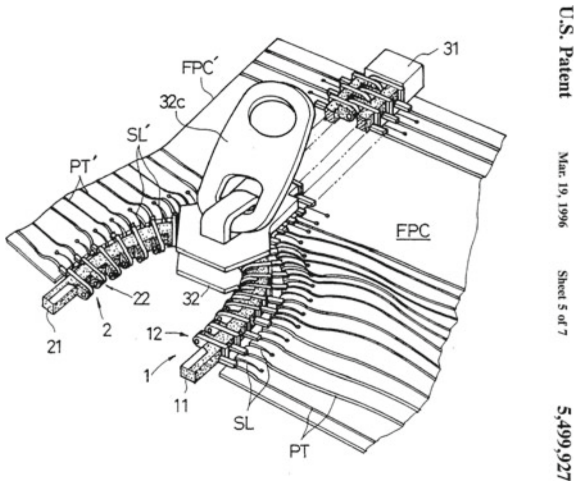

Fig. 9.5 Electrical connection through a zipper (Patent US 5499927 A)

9.4.5 Conductive Zipper

An electrical connector in the form of a zipper was proposed by Avery in 1953 (Patent US 2877439 A) and later refined by several others, e.g. Hayashi in 1994 (Patent US 5499927 A). In the latter, conductive and insulating "teeth" of the zipper alternates on each side, preventing short circuits between neighbouring lines. Each element (tooth) comprises of a conductive area, which touches the conductive area of the opposing element, while being surrounded by non-conductive material to ensure isolation between neighbouring elements, as depicted in Fig. 9.5.

9.5 Pocket Connector

A novel type of electronics-to-textile connector shall be presented in more detail. The connector was introduced by Mehmann et al. [31].

The principle of the pocket connector is depicted in Fig. 9.6. An electronic device is slid into a stretchable pocket. Similar to a ball-grid-array chip, the device has copper bumps in a matrix structure. The pocket contains conductive pads inside. When the device is inside the pocket, the copper bumps connect to the conductive pads of the pocket. Specifically, the principle with the conductive bumps is similar to zero insertion force (ZIF) ball grid arrays (BGAs) in circuit board assembly [32, 33]. When sized correctly, the stretchable pocket should keep the device in position and ensure contact and alignment. In order to distribute the pressure between all contacts, the device surface was curved.

The advantage of this design is the clear separation between textile and electronics. This facilitates the manufacturing of device and textile, as both textile and electronics

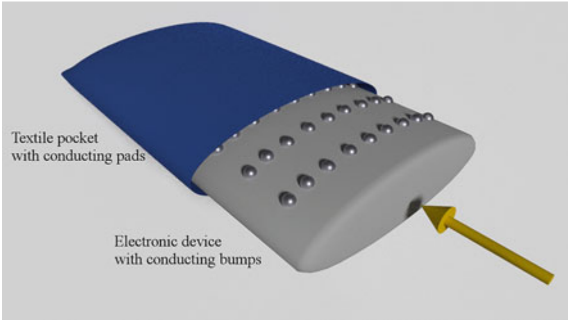

Fig. 9.6 Principle of ball-grid-array-like electronics-to-textile pocket connector. Conductive bumps are attached to the casing of the device. When slid into a pocket with conductive pads, bumps and pads align, forming electric contact ensured by the pressure caused by the stretch of the pocket

industry can apply their known fabrication processes and materials. Also, there are no rigid parts in the textile.

The device can easily be pulled out of the pocket and reinserted, enabling separate washing of the textile, charging of the battery or swapping of the device. Sliding the device in and out of the pocket conforms to common behaviour of smartphone users who carry their phone in a pocket.

9.5.1 Simulation of Contact Pressure

Electrical contact between the conductive pads on the textile and the conductive pads on the electronics device is ensured by mechanical pressure. The mechanical pressure is achieved by sliding the device into a stretchable pocket. The surface of the electronic device is curved in order to optimise contact pressure between bumps and pads in the middle of the device. To focus the pressure on the contact pads, small spherical conductive bumps were shaped on the device to contact the textile pads.

To investigate the effect of the shape on the mechanical pressure between textile and device, computer simulations based on a framework developed by Harms et al. were conducted [34]. The framework used a force-based particle model to simulate the force of a textile acting on a surface [35].

The simulations showed that the pressure between textile and device is highest along the edges. With a curved surface and bumps on the device, the pressure can be concentrated on the contact areas. With an elliptic surface and bumps of 0.7 mm, the force on the contact pads increases from 0.1 N, which is the pressure along the edges, to 0.3 N (see Fig. 9.7). When doubling the height of the solder bumps, the force also roughly doubles to 0.6 N, which is a factor of about 6 to 7 compared to the force along the edges.

To verify the simulation results, a measurement set-up with load cells was designed (see Fig. 9.8). With no bumps, there was no pressure measured. With 0.9 mm bumps, the measured force increased to 0.15 N. The deviations between measurements and simulations can be caused by a different young modulus of the neoprene, measurement uncertainties and fabrication deviations.

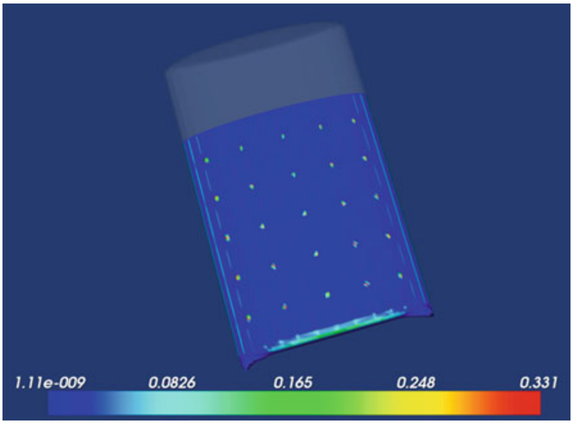

Fig. 9.7 Simulated pressure distribution on casing with bumps. The visible pressure spots are caused by the bumps

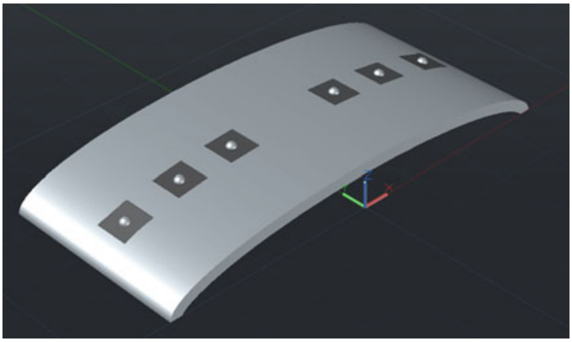

Fig. 9.8 Design model of 3D-printed casing with elliptic shape, containing load cells with 0.9 mm bumps to measure force. The casing is 35 mm long and 75 mm wide. The curvature is elliptic with 16 mm minor axis

9.5.2 Prototype

A prototype was built by Mehmann et al. with 56 connections on an area of 60×100 mm, which is roughly the size of a smartphone [31]. The device prototype is depicted in Fig. 9.9.

The pocket pads were made from woven metal threads in a polyester fabric. Stripes were separated into pads by punching holes in the fabric. The metal threads were 50-µm silver-coated copper filaments, and the polyester was a woven polyethylene

Fig. 9.9 3D-printed casing with attached flexible print with solder bumps. The casing is 100 mm long and 75 mm wide. The curvature is elliptic with 16 mm minor axis

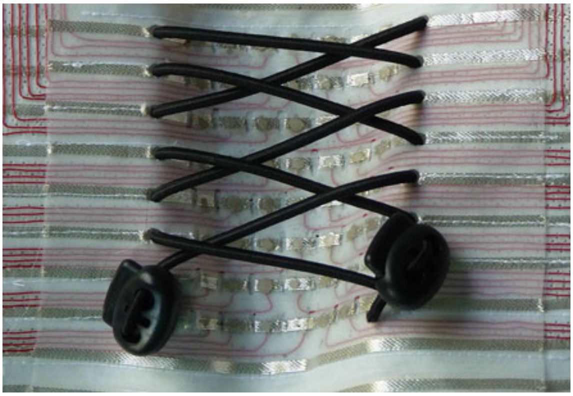

Fig. 9.10 Pocket version with elastic cords. This version allows the reader to see the conductive pads inside, while the elastic cords generate the pressure between textile and device

terephthalate (PET) from 64-μm monofilament fibres. A special weaving process was employed to ensure that the conductive threads were concentrated on one side of the fabric to improve the contacting between the textile pads and the solder bumps. The pads were connected to stitched copper cables with silver epoxy glue. The stitched copper cables are copper-stranded wires with a silver coating and 0.032 mm^2 cross section.

Figure 9.10 shows an open version of the pocket. The stretchability is achieved with elastic cords. Although the measurements were made with a closed pocket of neoprene, this version allows the reader to look inside the pocket and see the pads and the connection to the stitched wires.

While the described pocket connector design separates textile from electronics, some issues remain. During the insertion or removal of the device from the pocket, the bumps contact textile pads that are not assigned to them. This can result in damaged sensitive components when connected to the power supply. Also, the pocket can wrinkle. Two textile pads can then contact the same bump, causing a short circuit. To prevent this, software solutions to only operate the device when fully inserted can be implemented.

The durability of the fabric and device can be reduced due to sliding. The alignment and contact can be lost when using the device in harsh environments. For example, activities such as running or jumping imply higher strain and may introduce misalignment of the contact pads and solder bumps due to the shaking of the device. Furthermore, dirt and sweat can impair contacts. This can be impeded by the selection of the right textile material.

9.5.3 Measurements

After fabrication, the resistance of the prototype pocket connector was measured. The ohmic resistance of each connection at direct current was found to be less than 1.4 Ω

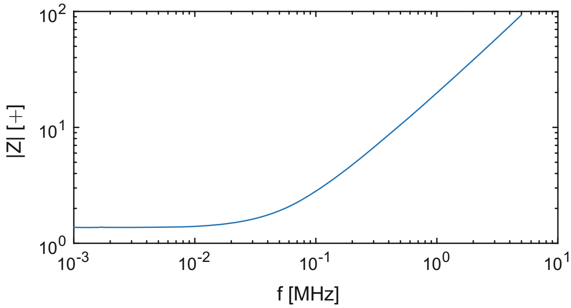

Fig. 9.11 Absolute value of impedance of connection depends on frequency. The inductive behaviour of the resistance results from the measurement set-up

and remains constant for frequencies below 10 kHz. This value is less than typically measured sensor resistances. In piezoresistive pressure sensing, the resistance is typically in the range of kΩ, and in bioimpedance sensing, the resistance is a few hundred Ω.

Figure 9.11 shows the impedance of the connection. At frequencies up to about 10 kHz, the constant 1.4 Ω can be observed. At higher frequencies, the resistance increases, which is due to the loop formed by the measurement set-up. The loop results in an inductive behaviour of the impedance measurements. Measuring only the conductive threads in the textile with the same measurement set-up gives similar results with slightly lower resistance values. The difference in resistance results mainly from the conductive epoxy.

9.6 Further Reading

A collection of do-it-yourself smart textile projects including various connectors can be found on kobakant.at/DIY.

Summary

In this chapter, various types of textile-to-electronics connectors are presented.

- Fixed connections include welding, soldering, mechanical fastening or adhesives.
- Removable connections can be done with hook and loop, snap fasteners, plug connectors, magnetic connectors or zippers.
- A pocket connector design separates textile and electronic device manufacturing.
- There is a trade-off between number of connections, size of rigid parts and ease of use.

Acknowledgements Part of this work was funded by the Simple Skin project from the European Union Seventh Framework Programme ([FP7/2007-2013]) under grant agreement no. 323849.

The pocket connector was developed in cooperation with two contributors. SEFAR, a Swiss textile company specialised in high precision fabrics for filtration, provided the fabrics, and Werner Gaschler and Peter Chabrecek provided helpful information on textile processing. Karl Gönner with the Institute of Textile Technology and Process Engineering (ITV) in Denkendorf did the textile integration.

References

1. Harman, G.G.: Wire Bonding in Microelectronics, 3rd edn. McGraw-Hill, New York (2010)
2. Russell, S.: Handbook of Nonwovens. Woodhead Publishing, Cambridge (2006)
3. Stokes, V.K.: Joining methods for plastics and plastic composites: an overview. Polym. Eng. Sci. **29**(19), 1310–1324 (1989)
4. Potente, H., Uebbing, M.: Friction welding of polyamides. Polym. Eng. Sci. **37**(4), 726–737 (1997)
5. Shi, W., Little, T.: Mechanisms of ultrasonic joining of textile materials. Intern. J. Cloth. Sci. Technol. **12**(5), 331–350 (2000)
6. Delannay, F., Froyen, L., Deruyttere, A.: The wetting of solids by molten metals and its relation to the preparation of metal-matrix composites composites. J. Mater. Sci. **22**(1), 1–16 (1987)
7. Puttlitz, K.J., Stalter, K.A.: Handbook of Lead-free Solder Technology for Microelectronic Assemblies. CRC Press, New York (2004)
8. Mei, Z., Hua, F., Glazer, J., Key, C.: Low temperature soldering. In: Twenty-First IEEE/CPMT International Electronics Manufacturing Technology Symposium, 1997, pp. 463–476 (1997)
9. Henkel: LOCTITE C 400 97SC 3C 1.63MM, 1 February 2016. http://hybris.cms.henkel.com/henkel/msdspdf?country=US&language=EN&matnr=673832
10. MG Chemicals: Sn96 Lead Free Solder (SAC 305) 4900, 1 February 2016. http://www.mgchemicals.com/products/solder/non-leaded/sn96-4900/
11. Glazer, J.: Metallurgy of low temperature pb-free solders for electronic assembly. Intern. Mater. Rev. **40**(2), 65–93 (1995)
12. Kinloch, A.: Adhesion and Adhesives: Science and Technology. Springer Science & Business Media, Heidelberg (2012)
13. Linz, T., von Krshiwoblozki, M., Walter, H., Foerster, P.: Contacting electronics to fabric circuits with nonconductive adhesive bonding. J. Text. Inst. **103**(10), 1139–1150 (2012)
14. Simonis, D.: Inventors and Inventions. vol. 2. Marshall Cavendish, Singapore (2008)
15. adafruit: Conductive Hook & Loop Tape (Velcro) - 3” long, 1 February 2016. https://www.adafruit.com/products/1324
16. Nanda, G.: Accessorizing with networks. Master’s thesis, massachusetts institute of technology (2005)
17. Seager, R., Chauraya, A., Zhang, S., Whittow, W., Vardaxoglou, Y.: Flexible radio frequency connectors for textile electronics. Electron. Lett. **49**(2), 1371–1373 (2013)
18. Prym: Sew-on snap fasteners, brass 6–11 mm, 1 February 2016. http://www.prym-consumer.com/prym/proc/docs/produktdb_en.html?article=341270
19. Lehn, D.I., Neely, C.W., Schoonover, K., Martin, T.L., Jones, M.T.: e-TAGs: e-textile attached gadgets. In: Proceedings of Communication Networks and Distributed Systems: Modeling and Simulation (2004)
20. Linz, T., Kallmayer, C., Aschenbrenner, R., Reichl, H.: New interconnection technologies for the integration of electronics on textile substrates. Ambience 2005 (2005)
21. Ngai, G., Chan, S.C., Ng, V.T., Cheung, J.C., Choy, S.S., Lau, W.W., Tse, J.T.: I*CATch: a scalable plug-n-play wearable computing framework for novices and children. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. CHI’10, New York, NY, USA, ACM, pp. 443–452 (2010)

22. Post, E.R., Orth, M.: Smart fabric, or wearable clothing. In: iswc, IEEE, p. 167 (1997)
23. Electronics, S.: LilyPad Arduino SimpleSnap., 7 April 2015. https://www.sparkfun.com/products/10941
24. Ohmatex: Washable textile connector, 20 December 2015. http://www.ohmatex.dk/?page_id=101
25. Wilson, T., Slade, J.: Development of non-standard wearable connectors for a usb 2.0 textile cable. Technical report, DTIC Document (2006)
26. hayeon: How to connect conductive thread ribbon cable with Flexible Flat Cable (FFC) connectors., 20 December 2015. http://www.instructables.com/id/How-to-connect-conductive-thread-ribbon-cable-with/
27. Apple: Apple 85W MagSafe 2 Power Adapter for MacBook Pro., 1 February 2016. http://www.apple.com/shop/product/MD506LL/A/apple-85w-magsafe-2-power-adapter-for-macbook-pro-with-retina-display
28. Vallese, J.: 'Break-away' cord aims to make deep fryers safer. *CNN*, July 4, 2001. http://edition.cnn.com/2001/US/07/03/deep.fryers/index.html. Accessed 1 Feb, 2016
29. Scheulen, K., Schwarz, A., Jockenhoevel, S.: Reversible contacting of smart textiles with adhesive bonded magnets. In: Proceedings of the 2013 International Symposium on Wearable Computers. ISWC'13, New York, NY, USA, ACM, pp. 131–132 (2013)
30. Righetti, X., Thalmann, D.: Proposition of a modular i2c-based wearable architecture. In: MELECON 2010 – 2010 15th IEEE Mediterranean Electrotechnical Conference, pp. 802–805 (2010)
31. Mehmann, A., Varga, M., Gönner, K., Tröster, G.: A ball-grid-array-like electronics-to-textile pocket connector for wearable electronics. In: Proceedings of the 2015 ACM International Symposium on Wearable Computers. ISWC'15, New York, NY, USA, ACM, pp. 57–60 (2015)
32. Kozel, C.: Zero insertion force miniature grid array socket., 10 June 1997 US Patent 5,637,008
33. Liu, W., Pecht, M.: IC Component Sockets. Wiley, New Jersey (2004)
34. Harms, H., Amft, O., Tröster, G.: Does loose fitting matter?: predicting sensor performance in smart garments. In: Proceedings of the 7th International Conference on Body Area Networks. BodyNets'12, pp. 1–4 (2012)
35. Volino, P., Magnenat-Thalmann, N.: Accurate garment prototyping and simulation. Comput. Aided Des. Appl. **2**(5), 645–654 (2005)