Joining technologies for electronic textiles

7

V. Mecnika[1], K. Scheulen[1], C.F. Anderson[2], M. Hörr[1], C. Breckenfelder[3]
[1]Institut fuer Textiltechnik (ITA) der RWTH Aachen University, Aachen, Germany, [2]Kanbar College of Design, Engineering, and Commerce, Philadelphia University, Philadelphia, PA, USA, [3]Hochschule Niederrhein—University of Applied Sciences, Mönchengladbach, Germany

7.1 Introduction

Since the first attempts at creating intelligent textile products, much effort has been devoted towards encouraging the development of smart textiles and bringing these discoveries to the market. At present, smart textiles play a significant role in multidisciplinary research by bringing together competences from different fields of engineering, information technology and design. Such textiles have eclectic applications, ranging from fashion to highly technical and specific medical solutions. Despite the variety of utilized materials, investigated structures and proposed manufacturing approaches, the prominent issue that characterizes all smart textiles is their ability to respond to and interact with the environment. The trigger, or stimulus, for smart textiles can be physical or chemical in its origins.

However, smart textiles can be generally described as a complex system that consists of two basic components. These include textile structures that carry specific functions and their corresponding electronic parts. In this case, the structure, which has an additional function, can be a textile sensor or actuator that ensures interaction with the environment through a physical or chemical reaction. The data regarding this interaction is transferred and processed in order to bring the acquired information to an application. Therefore, electronics are often an inseparable part of such smart systems. Correspondingly, the morphology of a smart textile unit is crucial in the development of such systems. Usually a unit has a multi-layer structure, which incorporates sensors, circuits, the infrastructure career, the protective layer and other relevant compounds.

In the current literature, breakthrough techniques have been developed for manufacturing textile interfaces, circuits, sensors and actuators. Textile engineering, information technology and electronics manufacturing have significantly succeeded in an attempt to bring advanced electronic textile solutions to vastly different applications. Indeed, some products that originated from the field of smart textiles are already found in the market. Nevertheless, many ideas are still at an initial stage of research due to a variety of technological and socio-economic barriers. One of the key issues in the development of electronic-based smart textiles is the investigation of how to bring together textile technologies with the desired electronics. The designed product should incorporate properties such as the flexibility and durability of textiles and the intelligence of electronics. Another challenge for smart textile

Electronic Textiles. http://dx.doi.org/10.1016/B978-0-08-100201-8.00008-4

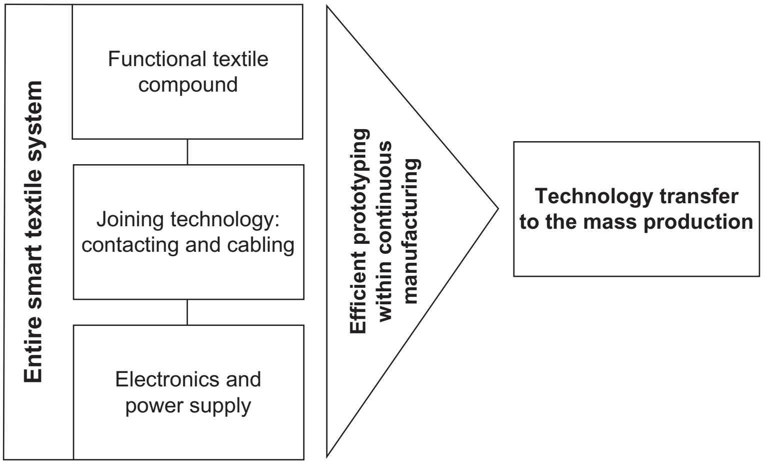


Figure 7.1 The positioning of joining technology as a bonding phase in smart textile development.

developers is efficiency enhancement and process optimization of multi-stage manufacturing. The proposed solutions for these objectives all relate to the type of joining technology utilized. Joining technology is crucial in smart textile production because it incorporates both critical elements: the smart textile component and the corresponding electronics (Figure 7.1). The method of joining and its corresponding technology depends on the desired function. These varying functions, which each have unique joining requirements, include background-information investigating topics like signal acquisition, heating and networking.

At present, there are a number of distinct concepts that ensure a functionally effective bonding of textiles with electronics. These approaches and their use-specific functions are often a compromise between materials and manufacturing technology. Selection of the method of bonding contributes to the function of the textiles.

Conventional textiles can be used to guide circuit wires and to control the electrical contact between the textile and components such as microchips, resistors and diodes. These techniques can be implemented by such technologies as embroidery, sewing or printing. On a more integrated level, textiles can be an inseparable component of the circuit wiring and contact systems as well. Due to the variety of electro-conductive materials, including monofilament metal wires and conductive yarns, conductive circuits can be implemented directly into the textile structure by technologies such as weaving and knitting. Generally, the solutions for textile bonding and electronic interfacing combine several approaches, in order to ensure a predictable, conductive and reliable wiring. These bonds, or interfaces, can even be designed as permanent or reversible. The former type of bonding can be ensured by techniques such as form locking or agent locking. Conventional textile technologies such as weaving, knitting, embroidery, sewing, crimping and staking can all be used in smart textile development in order to enable proper circuit wiring and contact between the textile and electronic units (Linz, 2012; Zesset et al., 2012; Zhang and Tao, 2012). Agent locking as a

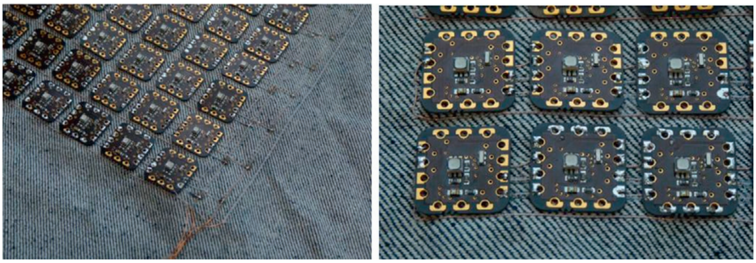


Figure 7.2 A matrix of electronic modules integrated onto textiles by embroidery and soldering (ITA, RWTH Aachen).

method of bonding in smart textiles can be also implemented more traditionally by soldering. For example, Figure 7.2 displays a combined approach to integrating a matrix of electronic modules on textiles. The wiring was initially developed by the tailored fibre placement (TFP) embroidery technique, using a metal monofilament. Then, solder was used to secure the electrical contacts of the electronic modules to the textile surface. Agent locking as a method of joining the electronics with the textiles can be also implemented by using adhesive bonding technology. Reliable contacts and secure connexions can be ensured by such conductive adhesive materials as silicone, polyurethane and epoxide-based films.

Another approach that focuses on non-conductive adhesive (NCA) bonding solutions was investigated by the research team at the Fraunhofer Institute (Krshiwoblozki, 2013). Reversible joining is beneficial for many smart textile applications where the functional modules must be detached from the textiles. Some researchers attempt to solve this issue by using fastener buttons, conductive Velcro, magnets and bolting.

Although there are many new smart textile solutions in development, they are mostly implemented at the prototyping stage. However, there are already solutions for joining technology promoted by smart textile developers for industrial applications. One of the crucial aspects of serial production is the automation of the manufacturing process. However, smart textiles were introduced to the market only a few years ago and are mostly produced in limited quantities (Horter, 2011). Continuous manufacturing of smart textiles can be ensured by such approaches as the pick-and-place technique and optimizing the production stages. At present, the development and transfer of such manufacturing tools to industry is relatively expensive, due to the limitations of the smart textile market. In fact, the complexity of the joining technology solutions corresponds directly with the development issues of a particular product. It is therefore integrally important to consider the limited market segment of smart textiles. Most of the products require distinctive manufacturing and processing scenarios that also include the electronic integration of the electronic components.

Although LEDs have limited functionality in textiles, they are a reliably simple tool to add desirable optical effects to textiles. For these applications, technical embroidery is a beneficial technology that ensures efficient and reliable manufacturing. For example, a Swiss company, Forster Rohner, has developed an embroidery-based approach to manufacture luxury interior textiles and clothing outfitted with integrated LEDs

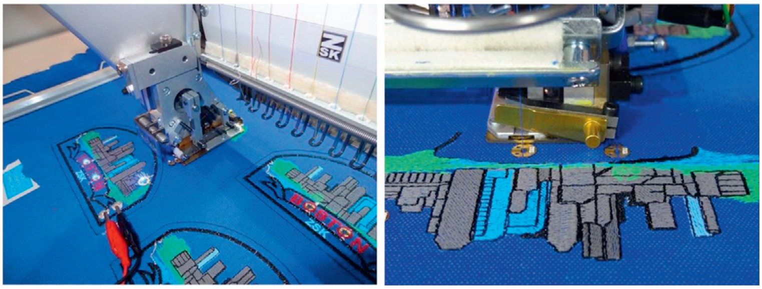


Figure 7.3 Automated attachment of LEDs by embroidery (ZSK Stickmaschinen GmbH).

(Zimmerman, 2013). ZSK Stickmaschinen and the research institute TITV Griez also demonstrate an efficient approach to the manufacturing of light-emitting textiles via embroidery technology and the application of LED sequins (Figure 7.3).

Beyond that, one of the promising markets for smart textiles is interactive systems. These systems often require more sophisticated joining solutions. At present, ready-made solutions for the interconnexion of the functional infrastructure are commercially available from companies such as Interactive Wear, Ohmatex and Clothing+. One of the common solutions to ensure interconnexion of the electronic compounds is textile cabling (Figure 7.4). Textile cables are usually built up from a textile ribbon with metal conductors. The contacts are soldered and processed to ensure mechanical protection by technologies such as hot-melt moulding. Manufacturing of such products consists of several stages. Some steps of the assembly, such as cutting the material and insuring proper contact protection, are fully automated and therefore supported by the programmed machines. Other operations such as soldering, tin coating and isolation are implemented by professionals and are tool assisted. For example, the electronic module in a large-area sensor system for Ambient Assisted Living, developed by Future Shape, is attached manually as a separate manufacturing step (Figure 7.5).

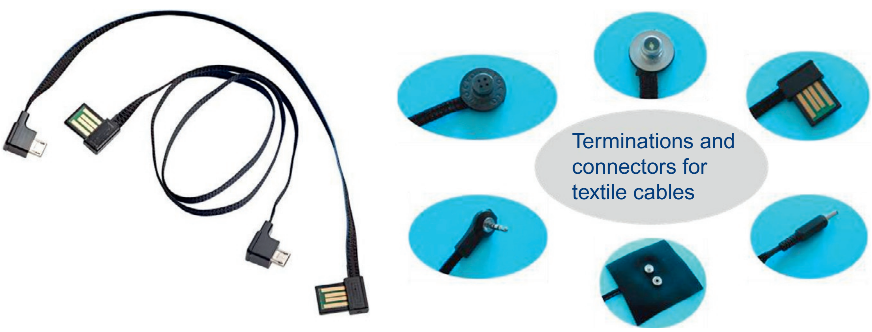


Figure 7.4 Textile ribbon cables and connexion elements (ZSK Stickmaschinen GmbH).

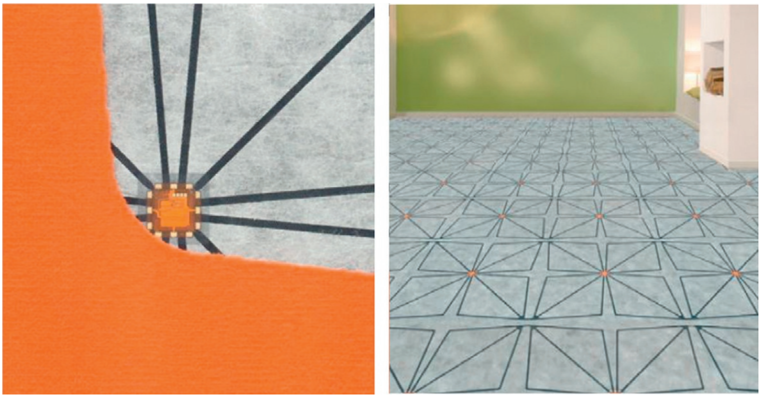


Figure 7.5 Integrated processing unit into large-area sensor SensFloor® system modules (Future Shape).

One of the main issues concerning the automated manufacturing of smart textiles is ensuring a continuous multi-stage process. At present, this key condition stays beyond the industry's manufacturability due to the limited-lot production of smart textiles. Transfer from manufacturing smart textiles in small series (100 pieces) to medium series (1000–5000 pieces) can significantly reduce product costs, by approximately 35–50%. A transfer to a middle-series production run requires different technological support and encourages the optimization of manufacturing techniques. However, automation of the particular operations is generally relevant to the functional, morphological and manufacturing issues involved in the specific product development. Moreover, the integration of automated manufacturing faces new barriers due to the lack of standardized manufacturing requirements for batch quantities of more than 100,000 a year.

This chapter reviews such beneficial techniques for joining technologies as embroidery and adhesive bonding. Finally, it addresses the problem of smart textile infrastructure development by building a multi-layer structure.

7.2 Joining by textile processing

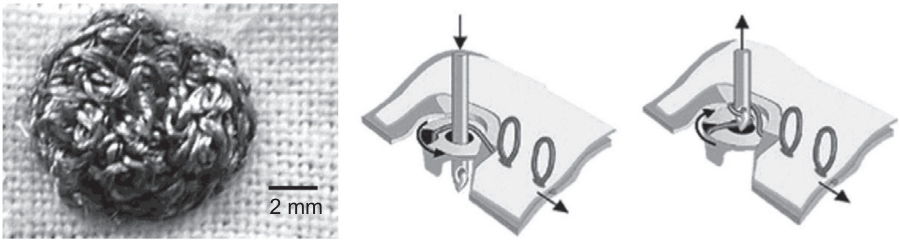
The connexions often used in smart textile development include categories like force-fit, form-fit or adhesive bonding. Form-fit connexions, primarily used for joining electronic devices to textiles, can be woven, sewed or embroidered. The advantage of embroidery is the possibility of using a single technology to combine the conductive paths with the supporting electronics in complex and useful geometries. Hence, embroidery is the only textile technology that can create devices like electrodes that consist of the creation of conductive paths and their corresponding connexions within the same manufacturing process.

7.2.1 Embroidery

Embroidery is a method that can be used to apply a given yarn material, or monofilament, to a textile substrate in a defined geometry (Gries and Klopp, 2007). Three kinds of embroidery methods are currently defined in the literature: chain stitch embroidery, standard embroidery and TFP.

7.2.1.1 Chain stitch embroidery (Ari)

The chain stitch, also known as the Ari stitch, is similar to crochet and is generally used for kettle and moss embroidery. Moss embroidery machines are built differently than traditional embroidery machines; however, they use a similar embroidery technique. Moss embroidery is created by a one-thread system. In this system, the needle goes through the carrier material and pulls the thread out from under the needle, plate side up (Figure 7.6). Then, a loop is created by a rotary motion of the needle on the upper side of the carrier material. Repeating this pattern frequently produces a moss-like surface.



(a) (b)

Figure 7.6 Chain stitch embroidery (Ari). (a) Textile electrode obtained by moss embroidery. (b) Principle of moss embroidery (ZSK Stickmaschinen GmbH, Krefeld, Germany).

7.2.1.2 Standard embroidery

The standard embroidery technique that includes a double lock stitch, also known as Sozni stitch, is a two-thread system. This type of pattern is first defined and punched in software. Following these definitions, it is then converted into embroidery machine code. The needle, or upper, thread is stored on a conical bobbin. The bobbin thread forms the stitches on the underside of the garment. The bobbin, or lower, thread holds the top embroidery thread to the garment. The basic fabric is held under tension through the use of an embroidery frame. This tension improves accuracy of the embroidery while also allowing for a clean and predictable stitch. During the embroidery process, the frame that secures the basic fabric is moved in the *x*- and *y*-directions in order to create the programmed pattern. The needle punches through the fabric and interlaces the upper thread with the bobbin thread by means of a rotating gripper located below the base fabric (Figure 7.7).

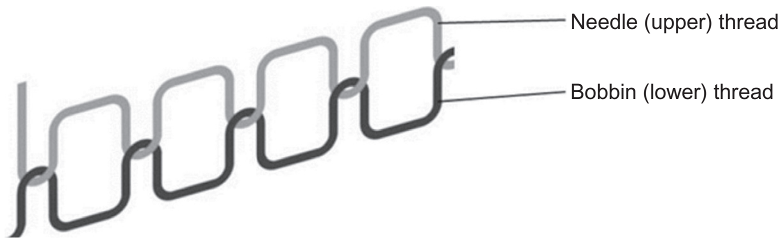


Figure 7.7 Double lock stitch—standard embroidery.

7.2.1.3 Tailored fibre placement

The TFP method consists of a three-thread system. TFP is a textile-manufacturing technique based on the principles used in sewing. This provides for a continuous placement of a selected roving material. This procedure is usually used in the composite industry for the optimization of material to fit customized loading conditions. The fibrous material is fixed by an upper and lower stitching thread onto a base material. Figure 7.8 shows the principle of the TFP method. A variety of fibres such as carbon, glass, basalt, aramid, natural, thermoplastic, ceramic and also metallic threads can be applied and combined within one preform. This creates limitless applications of TFP technology.

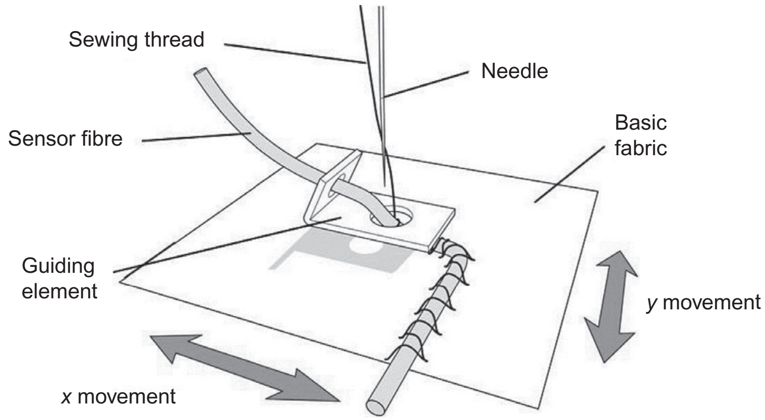


Figure 7.8 Basic principle driving tailored fibre placement (TFP) technologies.

7.2.2 Embroidery manufacturing

All three previously mentioned classes of embroidery are typically used when attempting to increase productivity in automated manufacturing. There are various machine configurations available, including up to 11 parallel embroidery heads for TFP and more than 56 parallel heads for standard embroidery (Figure 7.9). Due to this

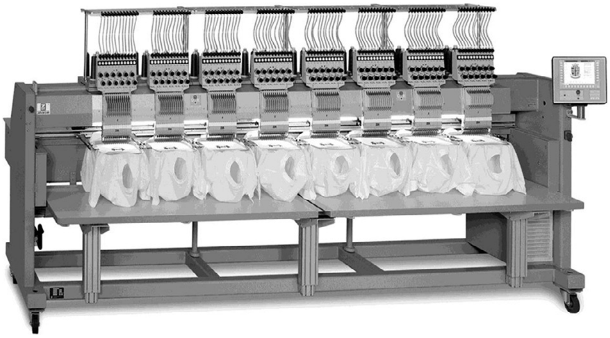


Figure 7.9 Tubular embroidery machine with eight heads (ZSK Stickmaschinen GmbH, Krefeld, Germany).

performance productivity, embroidery technology has decent efficiency when configured with other multi-head machineries. Potential applications of the technology range from decorative embroidery in carpeting or tablecloths to TFP embroidery for resistive automotive seat-heating systems. Due to these established embroidery applications, embroidery technology is poised to further functionalize textiles as a versatile joining technology.

7.2.3 Joining technology

The use of embroidery as a joining technology has been repeatedly demonstrated in the literature. Consistent research in this field has been investigated over the last decade. In 2006, Linz et al. investigated the utilization of embroidery in smart textile systems, publishing the paper 'Fully Integrated EKG Shirt based on Embroidered Electrical Interconnections with Conductive Yarn and Miniaturized Flexible Electronics' (Linz et al., 2006). In order to use embroidery technology as a joining technology, some methods have been established to help improve the system. Many preliminary investigations have shown that embroidered contacts are not intrinsically reliable. To ensure that the contact between the electronically conductive part and the textile lasts through washing, different solutions have been created to encapsulate the embroidered contact. It is believed that this encapsulation will help preserve the contact by limiting its interaction with water. This technique has been moderately successfully demonstrated for various temperature cycles and wash cycles. The results show that a combination of a local application of epoxy adhesive to the embroidered contact, combined with a subsequent encapsulation by hot melt, is necessary in order to provide a good electrical contact between the textile and the electronic parts (Linz et al., 2011).

However, all the previously mentioned investigations have had limited scope. This scope includes the observation that the sensors, actuators, electronics, printed circuit boards (PCBs) and conductive paths are on the same side of the fabric (see Figure 7.10). However, when embroidery is used, especially in near-body applications,

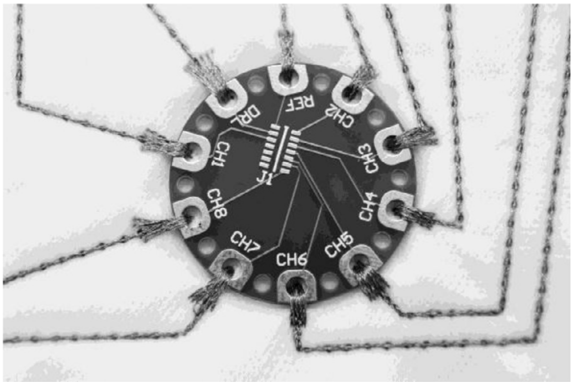


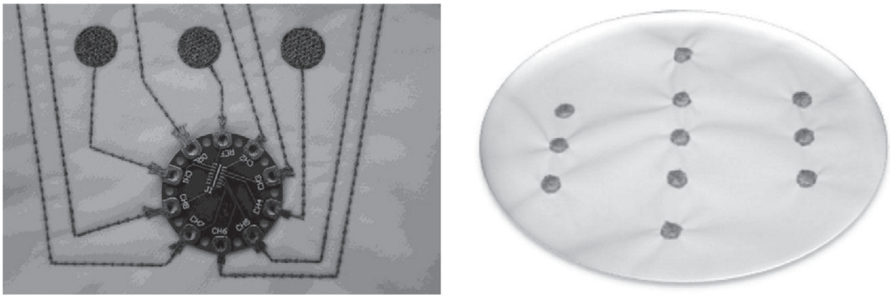
Figure 7.10 Joining of a PCB due to embroidery.

the placement of these separate system components influences the functionality of the entire system. More specifically, the electronic and conductive paths have to be placed on the outside of the fabric, as they generally should be shielded from naturally occurring conductive substances like sweat. Then the functional parts, like electrodes for sensors or actuators, are placed on the body side of the fabric, as they generally have to contact the skin directly. This placement is very important to ensure that the electrodes get the best skin contact, without being influenced by artefacts due to variations in the contact of the conductive paths with the skin. Therefore, the conductive parts have to be placed on the opposite side of the electrodes. All of the joining approaches previously mentioned and cited do not address this topic. The previous research has been primarily focussed on a one-side solution. Hence, the future of embroidery must focus on improving double-sided embroidery technology. These changes could have a radical impact on the ability to create new products in various textile markets. In order to detail the importance of this issue, an example application is depicted in the following sections.

7.2.4 Future trends in embroidery

Textile electrodes can be used for various types of bio-signal monitoring, including ECG, EEG and EMG. All of these resulting applications are primarily derived from the same technology. In these technologies, conductive electrode pads measure electrical signals, which are then transmitted through the textile's conductive paths to a circuit board for processing. Current trends such as flexible circuit boards are designed to be integrated and adapted directly into apparel. The advantages of this solution include improved comfort. The ultimate goal is to integrate the electronics and the electrodes in such a way that they can be hardly recognized or sensed by the user. This improves the user's experience.

To make sure that the electrodes are able to measure the smallest signals possible, they must be separated from exterior electromagnetic influences. Extraneous electromagnetic interference leads to artefacts that can reduce the signal-to-noise ratio and increase system errors. To ensure that the system is robust towards artefacts, the



(a) (b)

Figure 7.11 Embroidered EEG cap for epileptics. (a) Electrodes, conductive paths and circuit board (PCB) with all components on one side of the textile. (b) Embroidered electrodes without conductive paths and circuit board.

electrodes must be placed on the opposite side of the textile, which does not hold the conductive paths. The circuit board, even while being flexible, also must be placed on the side of the textile that does not contain the electrodes, in order to make sure that user comfort is acceptable. Additionally, this helps ensure that there are no extraneous signals due to contact between the circuit board and the skin.

Currently, embroidered solutions tend to focus on the joining and functionalization of the textile. They do not tend to focus on the particular placement and the process chain behind such a product. Therefore, several adaptations of the standard embroidery machine must be made in order to increase both utility and efficiency.

First, automatically altering the embroidery hoop dimensions could improve the possibility of online monitoring of the already embroidered geometry. This feedback control could eliminate many errors and conserve expensive materials like those used in the construction of electrodes. Figure 7.11a shows some electrodes for EEG monitoring with their embroidered conductive paths and a PCB joined by embroidery on one side of the textile. This is a typical application where the conductive paths and the PCB must be separated from the electrodes, shown in Figure 7.11b.

7.2.5 Technical challenges

To produce an automatically embroidered two-sided EEG cap with joined PCB, the production cycle, shown in Figure 7.12, should be fulfilled each time.

The challenges in this production cycle are manifold:

- Turnaround of the textile with 100% crashworthiness,
- Sinking of the frame into working position after turnaround,
- Correct placement of the PCB from a depot,
- Correct approach of the hole of the PCB in order to make the embroidered contacts.

The challenges of a turnaround of the textile with 100% crashworthiness are that the frame's position is directly between the needles and the bobbins (Figure 7.13a). Crashworthiness is defined as follows: when the frame is turning around, under

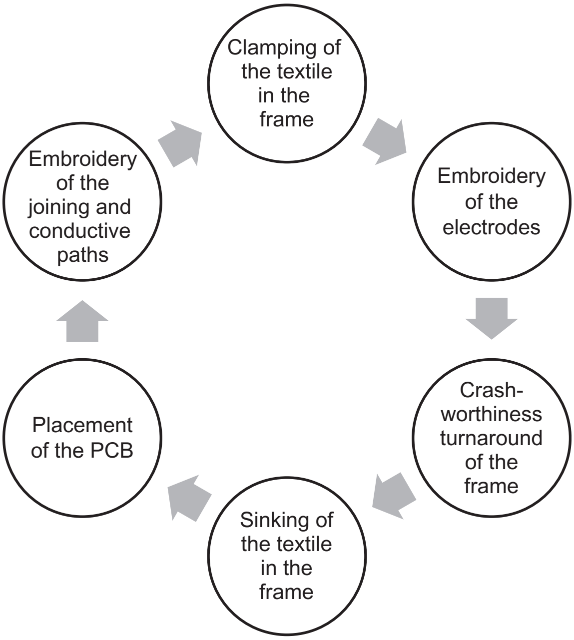


Figure 7.12 Production cycle of an automatically embroidered EEG cap.

any circumstances, the frame is not colliding or crashing in the needles or in another part of the machine.

To obtain a turnaround with acceptable crashworthiness, the frame must be driven outside of the operation area in front of the machine (Figure 7.13b). To guarantee that the frame has been placed away from the needles, a sensor must be placed on the frame to control its position before the turnaround.

In the following, the necessity of sinking the textile is described. Sinking is defined as follows: the textile frame has to be built in such a way that the distance change, which happens while turning around the frame, can be compensated. Figure 7.14a shows a tubular embroidery machine with a conventional tubular frame properly

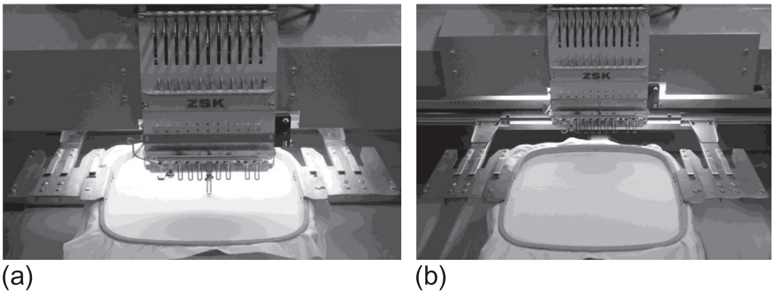


Figure 7.13 Tubular embroidery machine frame (a) in working position and (b) in turnaround position.

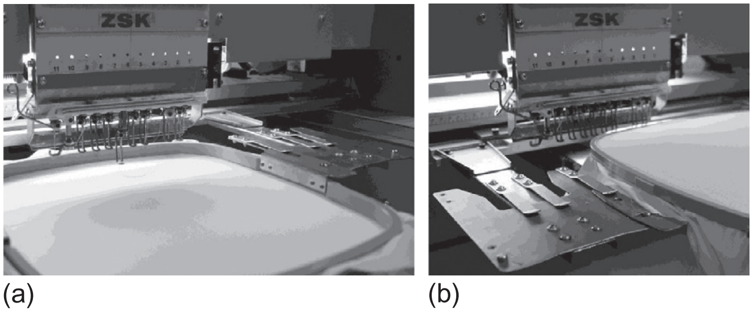


Figure 7.14 Distance between needle and textile using tubular embroidery (a) clamed in the right position and (b) clamed in the turnaround position.

clamped and secured. In Figure 7.14b, it is clamped while in a turnaround position. This comparison shows that this kind of frame can only be used to embroider on one side of the textile. A turnaround is not possible because of the change of distance between the needle and bobbin. This distance, the distance between the needle and the bobbin, has to be the same all the time during embroidery in order to ensure predictable results. Hence, a simple turnaround of the frame does not lead to a successful solution. The frame has to be constructed in a way that allows automatic turnaround and an automatic sinking of the textile to the proper working position.

The correct placement of the PCB is another technical challenge that must be solved in order to produce electronic textiles on a large scale. In order to place the PCB automatically, a sensor must be integrated in the embroidery system to guarantee the exact position of the PCBs from a central supply depot, which contains the stock PCBs. The sensor has to ensure that an angular rotation of the PCB is excluded. Therefore, the PCB has orientation holes (Figure 7.15). In three of these orientation holes, small spikes are inserted to hold the PCB in place for the first embroidery steps. Otherwise, the PCB could slide during the embroidery process and the needle could miss the connexion holes (Figure 7.15). Another benefit of the orientation spikes is that even small changes in position can lead to a break in the electrical connexion between the PCB and the conductive fibre. If properly secured in the initial embroidery steps, no additional adhesive for fixation of the PCB is needed.

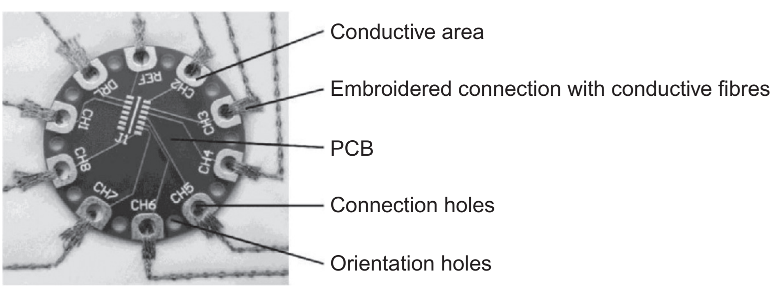


Figure 7.15 Connected PCB with conductive areas on a textile with conductive fibres.

7.3 Strategies and automatic approaches for textile joining

In the area of the cohesive joining technologies, the use of adhesive bonding is an attractive method for connecting different joining parts. Adhesive bonding's total potential is not fully realized yet, especially in the interfaces between textiles and electronic components.

In general, adhesive bonding describes the cohesive joining between two or more parts when using an adhesive material, the glue. Glue creates an adhesive connexion to the joining parts, due to adhesion between the molecules of the glue and the surface of each joining part. The adhesion mechanisms are mechanical, chemical or a combination of the two. In the case of mechanical adhesion, the connexion is created through form closure between the glue and the surface of the substrate. Chemical adhesion works through different chemical principles, such as van der Waals forces, covalent bonds, ionic bonds, metallic bonds and dipole bonds. The intensity of chemical bonding in glue forces depends directly on the substrate material and its surface properties. Here, the wetting of the glue strongly defines the degree of adhesion. The wetting is dependent on the surface energy of the substrate; the higher the surface energy, the higher the adhesion. In general, metals have a significantly higher surface energy, in the range of 1–2.5 J/m^2, than plastic. Plastic material values are generally much lower, in the range of 0.03–0.06 J/m^2. Therefore, plastic materials can generally be wetted less.

It is very important to have clean surfaces when using adhesive products; therefore, it is recommended to pretreat the substrates before use. The mechanical strength of the adhesive joint is defined by the adhesion to the substrates combined with the inner cohesion of the glue. The adhesive joint has the main task of ensuring the position between the joining partners. Occasionally, this adhesive joint has additional functionalities like conducting heat or resisting electricity. Each application requires adequate amounts of properly selected glue. These glues are selected specifically regarding the properties of the substrate material and also the requirements of the joint, such as mechanical strength, elasticity or additional functionalities.

In order to properly join textiles and their corresponding solid electronic components, different glues can be utilized. Therefore, it is important to detail how the electrical contact will be achieved. Three different strategies of producing electrical contacts are commonly used (Figure 7.16):

- NCA bonding, where electrical contact is made through a physical mechanical contact,
- Conductive adhesive bonding and electrical contact through the isotropic conductive adhesive (ICA),
- Combinations of conductive and non-conductive adhesive bonding and functional separation of mechanical strength and electrical conductivity.

For NCA bonding, thermoplastic melt adhesives are used normally because of their easy handling. A commonly used adhesive includes the class of thermoplastic polyurethanes. Also, conductive metal foils can be utilized when attempting to bond larger surfaces in shorter times. To achieve a reliable electrical contact, pressure is applied to

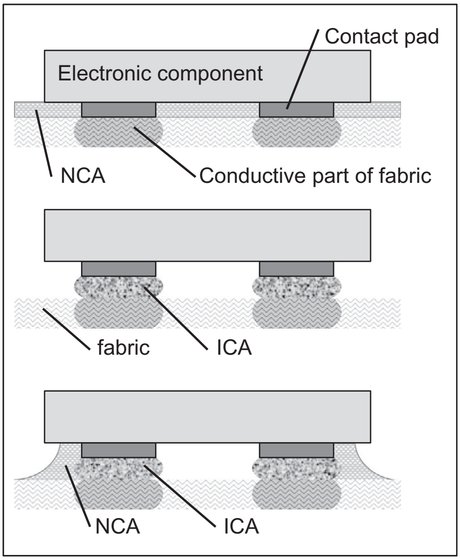


Figure 7.16 Different types of conductive joints.

the joining parts during the bonding process. The mechanical strength of these pressure-bonded parts is acceptable for most applications (Linz, 2012).

Epoxy-based conductive adhesives have also found widespread use in the engineering of smart textiles. Multiple base polymers can be used, such as other thermosets, elastomers or thermoplastics. Conductivity is achieved mostly through the addition of silver particles, which can have the form of flakes or powder with a size distribution between 1 and 30 μm. The percolation threshold at which the material receives its conductivity is between 70 and 85 wt.% (between 20 and 30 vol.%). This threshold is highly dependent on the particular particle systems integrated. ICA and anisotropic conductive adhesives were differentiated. In the area of smart textiles, most instances integrate ICA-based technology (Figure 7.17). The electrical conductivity of such adhesives is between 0.001 and 1 Ω cm and often depends highly on the curing process. The curing temperature is required to be between 100 and 150 °C, and the curing time is generally between 2 and 15 min. The mechanical strength of joints with conductive adhesives is relatively low, due to the high mass fraction of the conductive particles in the adhesive system. These particles generally weaken the adhesive.

Adhesive bonding utilizing a combination of conductive and non-conductive materials has been insufficiently explored. By researching the required functionality, including electrical conductivity and mechanical strength, an adhesive can be chosen to limit undesirable functionality while optimizing the function-desired properties. Additional questions regarding the integration of adhesives exist, including the process of applying the adhesives and questions regarding proper curing. The curing

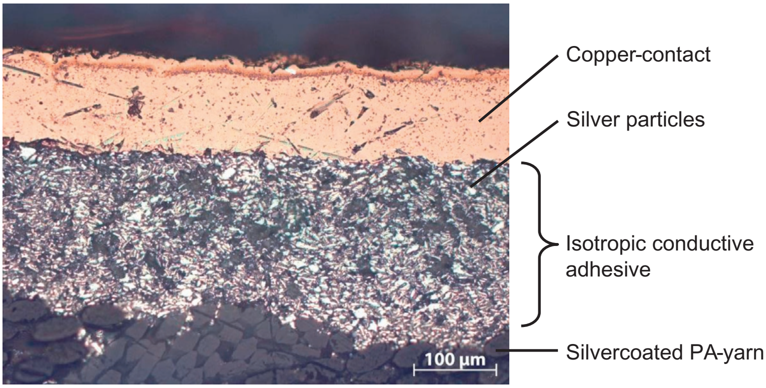


Figure 7.17 Joint between copper-contact and conductive fabric through ICA; silver particle content of 80 wt.%.

condition of the ICA is specifically important, as these curing temperatures can reduce the mechanical strength of the combined adhesives.

An example of such combined adhesives is the reversible contacting of smart textiles with adhesive-bonded magnets (Scheulen, 2013). Here, three different technical approaches were examined (Figure 7.18). Furthermore, questions investigated how neodymium magnets can be securely bonded to a conductive textile through an adhesive joint utilizing combined NCA and ICA. The NCA can be applied after the ICA process through the front gaps or from behind the textile substrate. In this way, it is not exposed to the damaging curing temperatures. Another possibility is to apply the NCA parallel with the ICA in order to reduce the possibility of negative impacts.

Every application determines the size of the bonding area, and the proportion that is the best compromise between mechanical strength and high electrical conductivity.

The compromise between adequate mechanical strength and high electrical conductivity can be improved through process evaluation in automated systems. This greatly assists in reproducibility, due to the automation. In automated processes, the textile substrate must be properly handled.

There are three major considerations when attempting to design and integrate smart-textile-based technology. These considerations include the handling of the textile substrate in order to prevent initial damage; the structure of the textile, including

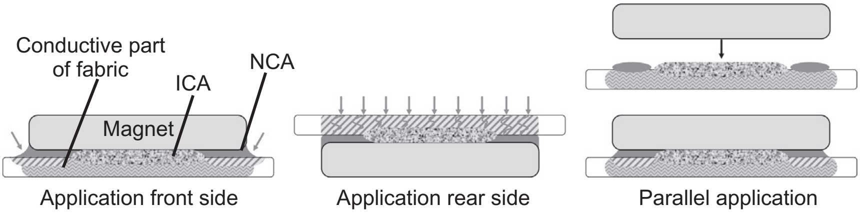


Figure 7.18 Three different ways to apply the NCA in combined joints with ICA.

position and number of conductive tracks; and the selection and application of a proper adhesive.

Currently, manual sheet-to-sheet handling of the substrate is most commonly used. Automated grabbing systems like a vacuum grabber are feasible, but expensive. While roll-to-roll feed is possible, it is not yet available due to the low needs of the industry. The first trials of this technology have been made by the research group of TITV e.V., Greiz, Germany. Automated systems, which often apply additional sensing elements like microelectronics or adhesive dispenser sensors, determine the exact position of the contacting points for the joints. Therefore, the handling processes must be accurately defined. Otherwise, sophisticated computer-controlled camera systems are required in order to detect the relevantly changing production parameters. This area is currently being heavily researched.

Standard adhesive application methods are insufficient when small amounts of adhesive are necessary. Dispenser units, working with air or extruder feed, are often used for the application of the adhesives. Here, the handling of the conductive adhesive is often limited because of the particle size. Another technology utilizes shaped adhesive films. This is an attractive way to produce a complex series. Non-shaped films can be used for non-conductive bonding through the use of pressure and heat.

Working with adhesives has a lot of advantages, and also some restrictions. The main restrictions are

- Conductive adhesives are expensive due to their high content of conductive particles, which consists of, for example, silver.
- The high conductivity comes with less mechanical strength.
- The storage of the adhesives is normally under cold and dry conditions, which cause higher costs.
- Non-single-use parts that have contact with the adhesives must be cleaned.
- For the whole applications process of non-film adhesives, additional equipment is necessary.
- Most conductive adhesives need an additional curing process through temperature or ultraviolet light.

Nevertheless, joining with adhesives bring some advantages that cannot be achieved by other technologies. These are, especially,

- Adjustable flexibility allows usage for multiple applications and requirements.
- The conductivity is suitable in a wide range, up to more than 0.001 Ω cm.
- Adhesives can be very good combined with each other or with other joining technologies.
- There is nearly no disposal, so the usage ratio is very high.
- Mechanical strength is good, especially regarding dynamic conditions.
- Automated processes with adhesives are possible and can be combined with processes of pretreatment or further steps like applying electric pieces via pick-and-place machines.

Glueing is a reliable joining technology that fulfils the functionality of both mechanically and electrically conductive connexions. Many adhesives and their corresponding application processes are available and should be chosen according to the functional requirements of the textile. Hereby, it is necessary to be aware of the whole processing chain that could potentially come with the use of adhesives. Overall, there are many advantages in using this joining technology, but also a few steps left to properly automate the process.

7.4 Future trends

The dominant trends for smart textile development are well known. One leading trend is concerned with various roll-to-roll production scenarios. In these scenarios, deepening the level of textile integration can greatly increase textile value. On the other hand, the system-based aspect of embedded smart textiles begins to take the limelight of new product development concepts. Increasing the textile value is closely connected with efforts to realize functionality directly in the textile structure. In practice, often a single textile layer keeps a special characteristic, but functionality is reached by the combination of several different layers, textile or non-textile. The requirement of continuous textile character and new functionality of smart textiles can be well fulfilled by multi-layer structures. The chainsaw protection trousers (Beringer and Hoffmann, 2012) are a simple example of this multi-layered concept. The sensors, required by the wearable system, were realized via a textile sensor layer. This layer was then situated beneath the outer fabric and on top of the conventional protective reinforcement inlay (Figure 7.19). The textile sensor layer could be delivered as a roll-to-roll commodity and confectioned along the system specifications.

An additional example of multi-layer structure is the design and arrangement of a temperature sensor in a firefighter protection glove (Breckenfelder et al., 2010). The combination of several textile layers with different material properties helps to achieve the specific characteristic function of the embedded sensor. Specific material

Figure 7.19 Multi-layer structure of the chainsaw protection trousers.
Source: Hohenstein Institutes.

layers covering the sensor enable the preferable conduction and resistance of heat. Hereby, the required reaction time of the sensor is adjustable. The use of the textile multi-layer structure reaches the operating requirements only.

The process of tailoring, including cutting and mandatory joining technologies, plays a key role in automatic assembly scenarios. Parameters for the use of textile half-finished products like tool change, cutting plan, size effect and feeding are crucial issues and must be handled consistently during the assembly process. The matrix structure to build electrical switches (Gries et al., 2002) shows the principal relevance of the discussed approach. The manufacture of a switch matrix, which is realized by different layers, demands specific tailoring parameters. The matrix consists of a grid with electrical contact points. The conductive grid could be produced in an arbitrary form and size. For the 3D preforming, there is a textile fabric with warp-knitted lamellar conduction lines. The switch matrix was finally tailored with a bottom layer with vertical conductive lines, and a top textile layer with horizontal conductive lines. Visible characters for the single buttons are stitched on the surface of the top layer. For further functionality, the required textile fabrics must be cut and well positioned in the structure. Markers or other positioning techniques are necessary for the realization of the aligned final multi-layer structure.

In the case of roll-to-roll production, there are typically redundant structures or follow-up patterns. These patterns can be used to establish joining technologies, which bridge unavoidable seams. It is possible to realize fabric functionality by precisely positioning the patterns. A couple of the most utilized joining processes are described in the previous sections. The particular joining strategy is contingent on specific functional constraints. The addressed joining technologies have common problems to be solved, including optimal cutting scopes, scalability and positioning. Joining problems of textile fabrics include the handling of the flexible and stretchable material, pucker-free work pieces and tool management.

These requirements are valid not only for apparel, but also especially in the case of textile-reinforced composites such as fibre-reinforced polymers (FRP). There is demand for reduced offcuts and contour-related construction elements. An example showing the increasing requirements for multi-layer joining highlights the following prototype of a carbon fibre antenna (Figure 7.20a). The structure of the antenna consists of two carbon FRP (CFRP) layers (top and bottom), and a middle dielectric layer made of glass FRP (GFRP). The layers have been conglutinated using epoxide resin glue.

The antenna is fed using a coaxial connector, as shown in Figure 7.20b. An ICA is used to electrically connect the upper and lower layers to the connector's respective inner and outer conductors.

The performance of the antenna is, to a great extent, dependent on the antenna's capability, the different electrode layers to centre, and accurately fitting in the production process. Even small deviations could immensely downgrade the quality of the antenna.

A technological answer to these challenges could be found in the complex questions discussed in Industry 4.0 scenarios. To support roll-to-roll production within the manufacturing process of textile fabrics, process information must be attached

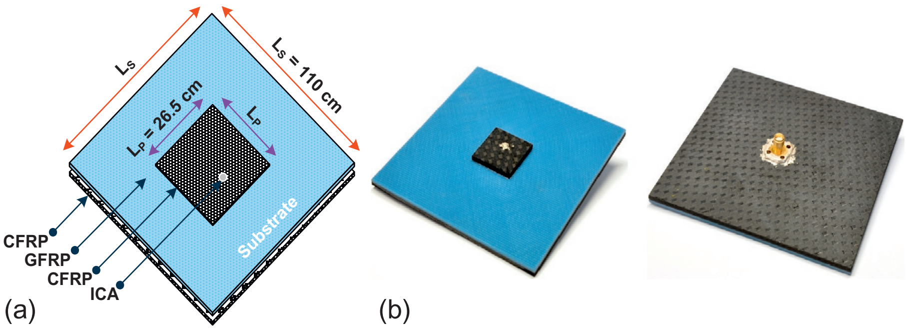


Figure 7.20 Multi-layer structure of a carbon fibre antenna. (a) A model of the antenna structure. (b) Fabricated prototype of the antenna (top view, bottom view). Shakhtour et al. (2013).

to the semi-finished textile product. This could be solved by a technology like micro-transponders. Transponder labels are currently available for textile applications. A recently offered technology, which seems to be excellently suited for future applications, is the E-Thread® technology (Vicard, 2014). The transponders contain the data of the specified functional layer, cutting tracks and sensorial scalability. For identification of the target position, appropriate structures within the fabric must be realized. These structures should allow the subsequent assembling machinery to allocate and execute joining procedures (Figure 7.21).

In general, composite components and mounting interfacing hybrid build-ups are used. Inserts are placed for the connexion elements, which are built in the fibre structure during manufacturing of the laminate and also applied on the surface as onserts. The resin of the textile-reinforced composite is used as an adhesive in order to realize a positive substance jointing for the force transmission. This is in conjunction with the

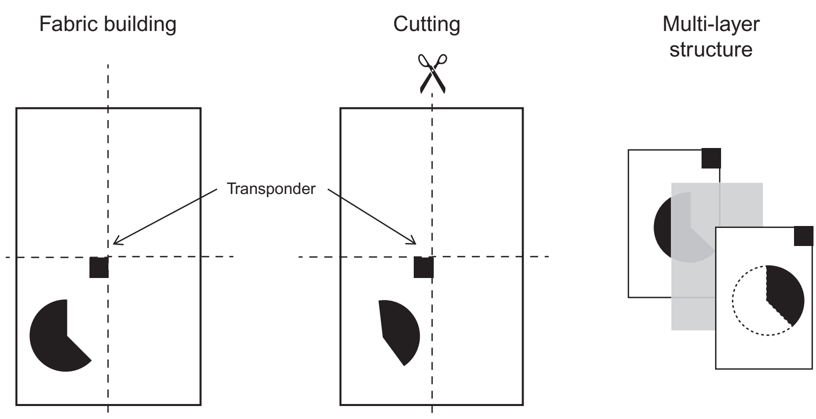


Figure 7.21 Multi-layer structure and transponder localization (principle sketch).

typical form-fit function. The specific combination of the material dictates the proper joining technology.

For the production of smart textiles, a consistently and closely interlocked value chain must be built up. This value chain allows one to adjust and hand over process parameter flexibly. Manufacturing and joining technology should be organized as a direct or joined process in order to achieve a reasonable and cost-efficient solution. Tool handling, cutting, feeding and removal of the textile for automatic assembly must be solved.

The approach should start with the recording of the customer's specifications by technical sale. In the first step, the semi-finished textile is produced. The information system collects the relevant products and process parameters. Then, a product identifier is given. The chip-package process of electronic assembling has access to the data and can automatically gear tailoring and mounting via product identification and traceability algorithms. The product delivery is bound with a product data set. This is available within the product radio-frequency identification (RFID) and evaluable in a production planning and control system. For further process steps, this information is reusable. Even for the addressed (embedded) function, this product data set of the smart textile could fulfil later configuration requirements.

Simultaneously, this data acquisition enables networking strategies for former single-process steps and a more flexible organization of supplier structures. Smart textiles could be supplied with retrievable product data by manufacturers at any point in the manufacturing process.

References

Beringer, J., Hoffmann, P., 2012. Sensorische Schutzbekleidung für die Forstarbeit mit Motorsägen. Hohenstein Innovationsbörse 2012. Hohenstein Institut für Textilinnovation gGmbH, Bönnigheim (21.06.12).

Breckenfelder, C., Mrugala, D., An, C., Timm-Giel, A., Görg, C., Herzog, O., Lang, W., 2010. A cognitive glove sensor network for fire fighters. In: López-Cózar, R., Aghajan, H., Augusto, J.C., Cook, D.J., O'Donoghue, J., Callaghan, V. et al., (Eds.), Workshop Proceedings of the 6th International Conference on Intelligent Environments. Ambient Intelligence and Smart Environments, vol. 8. IOS Press, Washington, DC, pp. S.158–S.169.

Gries, T., Klopp, K., 2007. Füge- und Oberflächentechnologien für Textilien. Verfahren und Anwendungen. Springer, Berlin.

Gries, T., Ramakers, R., Besen, A., 2002. Textile Schaltmatrix und Herstellungsverfahren dafür am 04.01.2002. Veröffentlichungsnr: DE 102 00 146 A1.

Horter, H., 2011. Entwicklung von kostengünstigen Aufbau- und Verbindungstechnologien für textilintegrierte Steckverbinder und Mikrosysteme. DITF, Denkendorf, pp. 3–9.

Krshiwoblozki, M., Torsten, L., Neudeck, C., Kallmayer, C., 2013. Electronics in Textiles – Adhesive Bonding Technology for Reliably Embedding Electronic Modules into Textile Circuits. In: Advances in Science and TechnologyVol. 85. pp. 1–10.

Linz, T., 2012. Analysis of Failure Mechanisms of Machine Embroidered Electrical Contacts and Solutions for Improved Reliability. University of Ghent, Belgium.

Linz, T., Kallmayer, C., Aschenbrenner, R., Reichl, H. (Eds.), 2006. Fully integrated EKG shirt based on embroidered electrical interconnections with conductive yarn and miniaturized flexible electronics. In: International Workshop on Wearable and Implantable Body Sensor Networks, 2006 (BSN 2006).

Linz, T., Simon, E.P., Walter, H., 2011. Modeling embroidered contacts for electronics in textiles. J. Text. Inst. 103 (6), 644–653.

Scheulen, K., Schwarz, A., Jockenhoevel, S., 2013. Reversible contacting of smart textiles with adhesive bonded magnets. In: Proceedings of the 2013 International Symposium on Wearable Computers (ISWC'13). ACM, New York, NY, USA, pp. 131–132.

Shakhtour, H., Heberling, D., Breckenfelder, C., 2013. Fiber-reinforced polymer based patch antenna for automotive and avionic applications. In: 35th ESA Antenna Workshop on Antenna and Free Space RF Measurements, 10–13 September 2013. ESTC, Noordwijk, The Netherlands.

Vicard, D., 2014. The E-Thread® Technology. Electronic in a yarn. Vorträge des 2. Anwenderforums "SMART TEXTILES". Zeulenroda (27.02.14).

Zesset, C., Kindekledei, T.W., Münzenrieder, N., et al., 2012. Integration method for electronics in woven textiles. IEEE Trans. Compon. Packag. Manuf. Technol. 2, 1107–1117.

Zhang, H., Tao, X.-M., 2012. A single-layer stitched electrotextile as flexible pressure mapping. J. Text. Inst. 103, 1151–1159.

Zimmerman, J., 2013. Technische Stickerei für die Produktion innovativer Textilien. Forster Rohner Textile Innovations, Intelligente Textilien, Bayern Innovativ, Lindau.