# An Overview of Textile Interfaces

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## ABSTRACT
In this paper, we aim to provide an overview on textile interfaces in regard to three main aspects: education, applied technologies and ways of interaction. The research in this field is still at an early stage and we find that there are a lot of opportunities for future work.

Textile interfaces offer a broad range of advantages to the educational world in terms of engagement, aesthetics and diversity, but still possess some drawbacks which need to be addressed.

The technology behind textile interfaces spread across several fields like electrical and computing engineering, but also sewing, fashion, and arts. The paper presents new technologies like piezoelectric materials and thermoelectric generator that helped the development of textile interfaces.

We also explore the interaction aspect of the field as we try to find out which gestures are acceptable and the criteria to make such choices.

## General Terms
Measurement, Documentation, Design, Reliability, Experimentation, Human Factors.

## Keywords
Textile interface, smart clothes.

## 1. INTRODUCTION
Smart materials are defined as “a set of sensors, actuators, and processing elements embedded in or attached to a fabric backplane which routes data and power throughout the textile” [1]. In other words, a smart material “can react to stimulus from its environment and adapt its behavior accordingly” [4]. Throughout this paper, we may refer to smart materials as smart clothes, electronic textiles, or e-textiles.

These smart clothes enable researchers to create a brand new area of interest: the textile interface, where e-textiles are used as an input or output device by a user.

When we look at the place of textile interfaces in the computing and HCI world, we see that they are “a platform for ubiquitous and wearable computing” [1]. Ubiquitous computing means that computers are integrated into everyday objects in such a way that they disappear from the consciousness. So smart clothes fit in this definition, as they can be inconspicuously integrated into a person’s daily life [1]. In addition, textile interfaces also comply with the characteristics of wearable computers; controls embedded into everyday clothing making them always accessible and it allows the user to carry on its usual activities while using the new functionalities of its garment [3].

Before textile interfaces appeared, smart clothes have been used for several applications, like health monitoring. In this case, sensors that are embedded in the clothes would monitor the user’s vitals and could transmit the data [12]. Moreover, most of the smart material uses are passive; they would record data using sensors, and possibly transmit it. However, the user has no interaction with the smart cloth.

An early attempt to overcome this which eventually led to textile interfaces was the Arctic suit [5]. This project was relying solely on electronic textiles, but it provided the user with a specifically designed interface device. Compared to the previous health monitoring jacket which had to interface for the user, the Arctic suit had a held-held device attached to the suit by a retractable cord. The Arctic suit can be considered as the “missing link” between e-textiles and textile interfaces.

One of the first real textile interface ever done was the Musical Jacket [9] (see Figure 1). A regular jacket was turned into a music instrument by adding an embroidered fabric keypad, a fabric bus and the required electronics on it. The keypad was a fabric switch matrix sewn from conducting and non conducting fabric. When a key was pressed, the two conducting layers would make contact through the spaces in the netting and an electric current would flow from a row electrode to a column electrode.


**Figure 1. The Musical Jacket [9]**

Like other platforms before, textile interfaces give an opportunity to expand creativity and to democratize IT, like programming languages or architecture principles. This will be shown in the later sections.

The object of this paper is to demonstrate how this new topic may benefit to the educational world, how its underlying technology works, and how interactions have to be rethought.

## 2. EDUCATION

In this section we investigate several applications of computational textiles in the education and we point out the major benefits that these have brought. We further describe the challenges of using smart materials in order to attract novices to technology.

### 2.1 Benefits

Wearable computing and e-textiles introduce an attractive approach for novices to explore technology as "expanding and democratizing the range of human expression and creativity" [2]. Several construction kits like Lilypad Arduino [2], TeeBoard [11] and i*CATch [10] were designed and used during workshop-based user studies aiming to engage young people into programming and electronics. All the participants in these workshops completed their projects by combining engineering and aesthetics, by putting creativity into making their own attractive fashion as part of their social appearance. Not surprisingly, integrating technology into the interests of the female students led also into increasing their enthusiasm for computer science and electrical engineering.

#### *2.1.1. Increase engagement*

Lilypad Arduino [2] was designed as a fabric-based construction kit that enables novices to design and build their own soft wearables and other textile artifacts [2]. It consists of a fabric-mounted microcontroller (see Figure 2), sensors and actuators connected by conductive threads. It can be seen as analogous to Lego Mindstroms as both construction kits consisted of input and output components but Lilypad Arduino aimed at the creation of interactive textile and Lego Mindstroms was applied for robotics [2].

**Figure 2. The Lilypad Arduino [2]**

The main goal of Lilypad Arduino was to teach children and novices fundamental skills in computer science and electronics by allowing them to creatively experiment with e-textiles. Most participants in a series of workshops lacked experience in these fields but were interested in others like art and crafts. A post study conducted survey showed an increased interest and engagement to the technology fields and six out of eight students expressed willingness to participate in future electronic fashion activities, where five of them would be inclined to take computer science and electrical engineering [2]. These results hint that textile-based ubiquitous computing can make science and technology more enjoyable than traditional teaching and thus broaden the engagement in engineering and computing [2]. Another credible evidence of the benefits of using e-textiles to attract young people to engineering was the fact, that three of the participants at Lilypad Arduino workshop returned to complete their projects or to add functionality after the end of the actual workshop (one of the participants, expressed unsolicited interest in an after school "electronic fashion club" and a more in-depth semester-long class) [2]. "E-textiles will probably not appeal to everyone, but they introduce the creative possibilities of computer science and electrical engineering in a unique way" [2].

**Figure 3. Spookies [4]**

Another researcher, Lena Berglin, addresses smart materials as a possible way to fill the gap between complex computational technology and understanding [4]. In her "Spookies" concept (see Figure 3), for example, she encourages the creativity and logical thinking of children in a free play. This interactive toy introduces several units that are to be operated as pairs to enable direct communication, to receive and display information, to detect and announce movements, to take and display pictures, play out melodies, to measure and handle time and distances, to send or receive code messages and to switch on/off light. Each unit is fitted with electronic components such as light detectors, vibrators, diodes, etc. and they communicate using wireless technology. Children may use their imagination and be spontaneous while playing with the units of the toy. Anyway, the combination of different "Spookies" opens up the opportunity for more complex functions and for a logic play with information technology [4]. To achieve this, the children should always keep in mind the hierarchy and possible combinations of the different units. They are encouraged to find their own rules for their play and interact among each other. By trying to be smarter than the competitors, logical thinking is stimulated and ensures richer and more engaging experience. Moreover, the interaction with the toy made children also curious to explore the technology behind it [4]. In other words, playing with the Spookies can motivate children to take engineering or computer science classes at a later point in their life.

#### *2.1.2. Art and engineering*

E-textiles are beneficial also to some other areas: fashion and aesthetics. The first one plays an important role especially in the lives of young people [2]. So wearable computing and smart textiles give them the opportunity to personalize their clothing in an attractive way, to express their personality and thus influence their social appearance in the society. They are tempted by the idea to create items, interesting applications of electrical engineering or computing, on their own that they will really use in their everyday life. For instance, a teenage girl at a Lilypad Arduino workshop created a touch-sensitive shirt that made sounds when someone squeezed her waist [2]. Not surprisingly, this shirt became an excuse for the teenagers to touch each other and they were flirting, fascinated by this “new game”. Therefore, e-textile and textile interfaces can have more than educational benefit as they can play an important role in the student´s life and can have an impact on their social appearance among their friends. This is one more reason why the design and aesthetics aspect have a crucial impact during the construction of textile interface.

At one of the workshops with Lilypad Arduino, students took advantage of the aesthetic affordances of the soft, multi-colored flower (being the microcontroller patch, see Figure 2) and utilized it as a decorative element. The kids spent a lot of time for the careful placement of electronic components and the precise sewing of the conductive threads trying to achieve better decoration [2]. In other words, “the “look" of the Lilypad deeply influences users´ experience of the kit” [2]. Moreover, students got encouraged to integrate aesthetics, art, design and engineering and thus reconnected these fields which intrinsically are not mutually exclusive.

### *2.1.3 Diversity*

Despite the above mentioned statement, it is a well-known fact, that the percentage of women in computer science is quite low. Some studies revealed that the problem lies in the lack of “communities and mentors that men have access to” [2]. Nevertheless, Lilypad Arduino can be seen as an unusual approach to computer science education [2] by integrating it into activities where women are already engaged or interested in. Moving the focus away from the technology and putting the stress on e-fashion is believed to be one of the reasons why more female students took part in the Lilypad Arduino workshops. So future educational programs should try to integrate the technology fields in a way that is attractive for young women.

## 2.2 Challenges

The nature of constructing e-textiles introduces some new challenges which need investigation in order to allow easy integration of wearable computing in technology education and to remove some of the obstacles for the integration of e-textiles into educational computing [11].

In the first place, sewing requires some basic level of skill. On the other hand, stitches are difficult to remove [2] and reassembling can be a time consuming task. Finding shortcuts and other conductivity problems after the sewing and attaching of components is done can cause the need to start from scratch all over again and it demands more time to be spent on the design and careful engineering [2]. So this emerges the need of a construction toolkit that supports active and hands-on learning by being easily reconfigurable and debuggable [11]. Nevertheless, the placement of microcontrollers, sensors and actuators and their connection through conductive thread combined with the aspect of aesthetics and usability may become a very cumbersome task. The later would lead to a situation where a significant amount of time is spent on building and decorating, while programming and debugging are left aside. That problem was addressed during the Lilypad Arduino workshop by forcing the students to detect errors and problems and begin programming at a relatively early stage [2].

One step into lowering the required level of sewing skill was to eliminate the use of conductive threads for the creation of connections between. The solution was introduced by Teeboard [11] – an education-friendly construction platform for e-textiles and wearable computing. It borrowed its approach from Orth et al. [18] and used conductive fabric to construct conductive strips [11]. This fabric has an adhesive backing and it requires simply to be ironed on top of a textile. Besides this, as the adhesive layer was non-conductive, users are able to create layered or crossing structures without having to care about short circuits. So it reduces also the need of advanced electrical knowledge.

Ngai et al. [10] addressed the challenge of the low-entry skills threshold with developing of the i*CATch wearable computing framework for children and novices. It meant to eliminate point-to-point connections, in which individual input and output pins on the microcontroller and the peripheral modules are connected directly to each other [10] as this technique required huge forward planning. It required also understanding the difference between open and closed circuits, avoiding short circuits and knowing how to connect devices in parallel and serial configurations – such knowledge and experience that novices lacked.

i*CATch construction platform [10] relies on a bus architecture where messages between components are send on a broadcast manner. So, in this case the communication requires only two channels and thus only two connection points for each electronic module. The interface of i*CATch made use of metal snap fasteners (see Figure 4). The idea of using snap buttons as connective interface [11] was developed already for the Teeboard. These fasteners have the advantage of being very robust [10], easily attached to the fabric and supporting multiple connect/disconnect cycles [11]. In this way, the durability and flexibility were granted. The challenge of creating error-prone electrical connection was also prevented as male and female snap fasteners allowed easy distinguishing of power supply and ground streams. The snap buttons made the task of module attachment also far easy than in other wearable computing frameworks. As a result, errors in the electrical engineering were easily reduced. The use of snap fasteners also supported the aesthetical aspect of the clothes.

By simplifying the hardware for wearable computing and lowering the skills threshold in the beginning, i*CATch encouraged the creativity of the participating students, they integrated more electronic modules and were able to spent more time on programming that lead to longer code. Despite this, the framework itself and its IDE encourages good programming practices, like code reuse, divide-and-conquer coding strategies and modular design [10]. The plug-and-play construction [10], on the other hand, allowed the novices to experiment and partially to use more iterative approach in the design phase.

For coding purposes, the i*CATch research group created a hybrid text-graphical programming language [10] and developed their own integrated development environment (IDE) for it. Programming uses dragging and dropping graphical blocks that represent programming constructs and joining them together to denote program flow [10]. The source code is generated in the background and the user can always switch to text-based programming whenever he or she feels confident into going one step further.

The Lilypad Arduino toolkit also comes with its own programming tool, a modified version of the Arduino IDE, which enables the user to program the microcontroller by plugging the PCB to a computer by USB, instead of removing the chip and plugging it to a special board linked to the computer [2]. This simplifies the programming tasks, but still requires programming skills from the user.

The Spookies project discovered other challenges different from those mentioned earlier. The main concerns to be reviewed were the look, form, and weight of the units because these factors influenced the active play of the children and how they perceived the toys. For example, a look of a pet "made some children to start taking care of the unit instead of participating in the game" [4]. Using very light balls had the natural affordance to be easily thrown. Thus the concepts of Spookies were reviewed several times to achieve successful stimulation of the active play.

In order to round up the challenges in e-textile technology education it is necessary to mention that wearable computing-related workshops usually lasted one week. This turned out to be quite a challenging time constraint for successful teaching a wide range of skills, e.g. sewing, electronics, programming. So completing a related project was additionally a hard task to be achieved.

# 3. TECHNOLOGY

In this section, we will go over the several challenges that are faced when developing the technology behind textile interfaces, the advantages that textile interfaces might have over other types of interfaces and we will describe some of the available hardware and software.

## 3.1 Challenges

A textile interface, as its name says, relies heavily on fabrics. Thus, in comparison to traditional electrical or computing engineering, some additional requirements have to be fulfilled, along with the traditional ones.

### *3.1.1 Traditional Constraints*

In mobile devices, the most common challenge that is usually met is the power consumption. Having a mobile device means that it must be battery operated and thus, several questions have to be raised at the design stage.

One issue can be the balance between functionality and power that has to be carefully thought before hand. Early projects like the Georgia Tech Wearable Motherboard [13] or the Arctic suit [5] used a large amount of processing power and needed large batteries. However, the battery weight needs also to be taken into account. Although it is already a concern when designing mobile devices like laptops or mobile phones, it becomes a major issue in wearable computing. For example, in the Arctic suit project, the designers chose not to exceed 1 kg extra weight for an original suit of 3.5 kg.

Besides the battery issue, in textile interfaces, like in any other project involving electricity, other basic electric considerations have to be taken into account. For instance, working with textile material means that there is a very large area that is available to sew electric wires. However, having this large space can create other problems like internal resistance if the wires are too long [10]. When trying to shorten the wires, on the other hand, one can create another problem by crossing connection lines [10] and generate short-circuits.

### *3.1.2 New Constraints*

Adding electronics to a piece of clothing is not a trivial task as it seems to be. Several aspects have to be considered, and the most important one is to make sure that the wearability will not be altered and that the original properties of the clothes will be kept.

In order to achieve this, attention has to be given to the location of the components; the weight must not be too important but must be appropriately distributed on the garment [5]. When placing visible components, extra care has to be given to aesthetics – as we stated in the education section — and to social aspects like acceptability. This will be discussed later in the interaction section. Also, the wiring must be done so that usual movements do not feel cumbersome, and it must resist to a certain amount of stretching [5].

Another obvious issue to be considered is that clothes usually require washing. When building a textile interface system, one must think that components which are embedded into the textile's structure will need to be washable, while components which can be removed must have an easy and robust way to be detached and reattached [5]. The i*CATch [10] platform solves this issue by using snap fasteners (see Figure 4) to attach electronic components to the textile. This way, the connection is secure and the garment can withstand several connect/disconnect cycles.

**Figure 4. Metal snap fasteners from [10]**

So textile interfaces' designers must pay attention also to some durability issues, like dropping, moisture, static charge, or wear and tear [1]. People take usually less care to their clothes than to their electronic devices, so it is the designers' job to make sure that textile interfaces can stand the test of time in an everyday life. Designers also have to take into account special constraints; depending on which situation and for what purpose a textile interface is used. For example, when developing the Arctic suit, the designers had to make sure the system could be used while wearing gloves and by left or right-handed people [5].

## 3.2 Advantages

As it was stated before, clothes are perfect for wearable and ubiquitous computing and thus have several advantages.

### *3.2.1 Ease-of-use*

Clothes with textile interfaces can be seemingly brought into a person's life, along with their extra capabilities. In comparison to an independent device, the deployment of a textile interface is trivial: the components are already in place, and the user has just to wear the piece of clothing to setup the added functionalities.

Another advantage over stand alone devices is that the wires are weaved or embroidered in the fabric, so it is not possible for them to become entangled or ripped off by accident.

### *3.2.2 Wired Over Wireless Communications*

Another unquestionable advantage of textile interfaces and electronic textiles in general is their capability to connect the components using wires instead of wireless systems.

First of all, from a power consumption point of view, the benefits are numerous. In a wireless architecture, in order to supply power to all of the independent components, several batteries have to be integrated to the garment [1], increasing the risk of losing wearability by adding extra weight. Furthermore, recharging the device becomes more complicated, as every battery has to be located so that it is easy to be replaced or plugged in.

Also, wireless communication means that components need to be actively listening all the time, which induces higher power consumption. In a wired system, components can be sleeping and awaken by an electric signal sent through the wires [1]. This way, unused components do not waste excessive amount of power.

Considering the wireless use, some user's concerns arise too [1]. From a security aspect, wireless transmissions raise privacy issues; the data being exchanged can be very personal [1], like vital signs monitoring, or these signals could be used to determine the user's location [1] and allow tracking him.

### *3.2.3 Power*

As we have seen in the above section, textile interfaces rely on a wired architecture, which allows better power consumption and limit the number of individual batteries. In comparison to other wearable computing systems, in e-textiles it is possible to include different power sources instead of only batteries.

As an alternative, when using a piece of clothing like a shirt, one can use body heat for power generation. Vladimir Leonov and Ruud J. M. Vullers describe [15] a "Body-powered system in clothing", an electrocardiography (ECG) system integrated into a shirt, and powered by a thermoelectric generator (TEG). The TEG is converting the heat flow into electricity. The incorporated battery is continuously recharged using the person's body heat, which is harvested using fourteen thermoelectric modules.

Another way is to take advantage of the large area of the textile by using multiple photovoltaic materials. These can be added to the garment and provide extra power. Konarka Technologies [14], a US company, developed several products, the latest one being Power Plastic®, a "photovoltaic material that captures both indoor and outdoor light and converts it into direct current (DC) electrical energy" [14]. This material is very fine, 0.5mm thick and flexible, and could be easily attached to a garment, or a clothing accessory like a bag. The ECG shirt presented above also contains photovoltaic cells, preventing the shirt's battery to be discharged if the shirt is not worn for months.

The third possible alternate source of power for a textile interface comes from body motion. This energy can be harvested in several ways. The impact forces generated while walking can be used by heel-strike generators, inertial forces in shoes or backpacks using electromagnetic induction or any movement can produce energy using a generator based on the self-winding wristwatch [16].

### *3.2.4 Fault-Tolerant Networking*

E-textile may easily overcome also other traditional constraints. For example, fault-tolerant networking can be achieved without difficulty, as "the large surface area of textiles offers the potential for incorporating redundant conductive fibers and components" [1]. In this case, only the cost factor and the power consumption influence the level of redundancy to integrate in the design.

## 3.3 Hardware

Textile interfaces are built using different techniques, components and tools available. The two main production techniques are embroidery and weaving and these have their advantages and disadvantages which we will present and compare below. In addition, we will shortly look what classification and kinds of materials exists for realizing fabric interfaces and will show what architectures are currently applied.

### *3.3.1 Embroidery*

The main advantage of embroidery over weaving is that any pattern can be created [1]; the conductive threads can be placed anywhere on the garment, in any direction, while in weaving, threads can only be placed horizontally or vertically. This allows for more liberty when designing a textile interface. The second main advantage embroidery has in comparison to weaving is that the conductive threads can be added on a finished piece of cloth as well [1].

However, one of the disadvantages of embroidery is that not any conductive thread can be sewn this way. It is important to check whether the type and size of the fibers will work with the machines [1]. The yarns must be strong and flexible in order to not break when sewn by the high speed machines [9]. These embroidery techniques were used to build one of the early examples of textile interfaces — the Musical Jacket [9] presented in the introduction.

### *3.3.2 Weaving*

Even though embroidery has several advantages, it cannot compete against weaving in respect of speed, due to the modern looms used for producing textiles.

Here is how the weaving process works in a few words [1]; two sets of yarn are used, one vertical, the other horizontal. One of these set, the warp, is attached to a loom, while the other, the weft are inserted perpendicularly during the weaving process. Before the weft is inserted, the loom orders the warp yarns so that the weft will run above or under them. These choices create the pattern. In a weaving process, the threads endure less stress than in embroidery, so the array of conductive threads that can be used is larger.

Weaving is the most cost-effective way of mass producing textile. However, changing patterns requires reconfiguring the machines, which is an expensive task, so the authors of [1] suggest using generic patterns on which several different systems could be built and using embroidery techniques to finalize the product.

### *3.3.3 Groups of Smart Materials*

Regardless of the production technique, smart materials are pieces of clothing enhanced with sensors or actuators and depending on their utilization, the following classification can be done [4]. The *passive* ones have only sensors which monitor their environment.

The smart activity bag [8] from Park et al. can be seen as an object using only passive smart materials, as it can only "sense" items that are in the bag, and indicate what items are missing by providing an indication or a reminder.

The *active* and *very smart* materials use both sensors and actuators which can react to stimuli coming from the environment. As an example we can consider the tracker pair of Spookies, where each unit tracks the distance range of the other unit and adapts the light indication in respect to the actual value.

### *3.3.4 Kinds of Material*

In the previous section we mentioned that often sensors and actuators enhance fabrics in order to achieve certain functionality. Textile interfaces systems may use several kinds of other components. Detecting a touch can be achieved in several ways, the obvious one being to use a regular button. However, other techniques are also available.

Instead of a regular button, one can use its textile equivalent; two layers of conducting fabrics are separated by a non-conductive layer, and when pressed, the outer layers will make contact and transmit an electrical signal [1], [4]. This is the technology used by the Musical Jacket's keyboard [1].

The touch of a finger can also be detected via a thermocouple material [4] which transforms a thermal signal into an electrical one. It can be detected by capacitive material [3] which reacts to the finger's electrical properties. This is the technology behind most multitouch screens, including the iPhone.

Another button equivalence can be obtained using piezoelectric materials. Piezoelectricity is electricity that is generated from pressure. This effect is present in some materials like crystals or ceramics [17]. Piezoelectrics react to a broad range of type and magnitude of physical stimuli like pressure or torsion. Pressing a piezoelectric material will generate an electric current, whose intensity depends on the exerted pressure, and it can be used as an input device. Piezoelectrics can also be used to generate power, if embedded in the sole of a shoe for instance [17], thus eliminating the need to manually recharge the batteries, which annoys most users [3].

Textile interfaces can implement other controls than buttons through special properties of fabrics. For example, shape memory materials use heat or electricity to revert to a predetermined shape [4], while chromic materials can change color in response from a special stimulus like temperature, light, pressure, electricity [4]… For instance, a part of a shirt could change color to require the user's attention in a more discrete way than by using a vibrator or a sound.

### *3.3.5 Evolution*

The first projects working on textile interfaces faced the same problem: how to deal with bulky electronic components? Electronic systems need a printed circuit board (PCB) with some components, circuit traces and component connection points.

Traditionally, PCBs are made on a hard substrate and these proved [9] to be inconvenient as clothes usually require being flexible. Flexible substrates have been tested [9], but were also dissatisfactory. They can bend along predetermined joints, but clothes can be crumpled, and these PCBs could be damaged. Nowadays, fabric PCBs are used. A fabric PCB is "a cloth printed circuit board made out of a combination of traditional and electrically conductive fabrics" [2]. They possess tabs and by sewing through them one can connect components. This method was used also in Lilypad Arduino toolkits and eliminated the need of soldering that could damage the threads.

Earlier fabric PCBs were square and tried to be as small as possible. However, studies showed [2] that these requirements were not essential for fabric PCBs, which led to create round fabric PCBs, with better aesthetics and sew-ability [2]. Besides this, it may also be possible to replace components like capacitors or resistors by using combinations of conductive thread with different electrical properties [9].

### *3.3.6 System Architecture*

When creating a textile interface system, before thinking about conductive threads and components, one has to choose between suitable architecture: either point-to-point architecture, which is the most popular choice (the Lilypad uses such an architecture), or a broadcast-based architecture. We will present the key characteristics of both methods and explain how a system with a broadcast-based architecture might be easier to build.

On the one hand, in a point-to-point architecture, every module has to be directly connected to the microcontroller by a dedicated line [10]. This has a direct impact on the cost of error correction. For instance, changing a component's position may require redoing the stitching or connecting it to another pin on the microcontroller and updating the code [10]. In a complex system with several components, each element needs to be connected to the microcontroller with several wires, and it may be difficult to avoid crossing connection lines [10] and to follow a particular thread when debugging.

On the other hand, a broadcast-based architecture aims at simplifying the electrical design and shrinking the number of connection lines. On such systems, all the devices are connected to a common communication channel and messages to and from the microcontroller are broadcasted [10]. This way, only one communication bus and a power supply line are needed. However, using a broadcast-based system adds some complexity. Each component must have a unique identifier, and messages exchanged will have an overhead with information about the sender and the recipient [10]. This overhead will need mechanisms to prevent message collisions, when several components try to transmit at the same time [10].

All in all, developing textile interfaces may be easier with a broadcast-based architecture, as it removes most of the wiring issues, in exchange for a little added complexity.

## 4. INTERACTION

Textiles reveal new ways of interaction and may support future innovative applications in the area of ubiquitous computing. The fabric can be used "as a communication medium, an information content platform or an interface"[5]. Smart garments may change their shape or color, may take advantage of LEDs for visual feedback. The diverse variations and technologies uncover numerous interaction opportunities. However, the operational environment also influences the interaction methods and challenges the natural mappings, the reachability, the social acceptability or the look and feel of a textile interface. In the following subsections we provide a deeper insight to some of the above mentioned points.

## 4.1 Type

When using e-textiles, there are several ways to interact with them: some of them are used as input for data or commands, while others simply provide visual, tactile or haptic feedback.

### *4.1.1 Dimensionality of input*

In general, the unquestioned advantage of wearable computing is that it can provide multidimensional input beside the two-dimensional one of buttons and thus offering some more complex interaction techniques.

Students in the Lilypad Arduino project employed both binary and multidimensional input. One of them, for example, created a sweatshirt which LED color changed in response to arm gestures [2]. Some students applied a binary type of input. A girl decorated a handbag [2] with touch sensitive patches that were used to switch a LED on or off. Another child built a binary switch to turn on and off the siren of his New York Police Department hat [2].

Another interesting example of interaction is the Reima Smart Shout [5] that introduced an innovative method for group communication in active situations like snowboarding or rock climbing. In these situations, exchanging information is hard and often reduces to shouting. Traditional use of mobile phones is also not feasible. The device, which the researcher group developed, consists of a two-inch wide textile band which is worn over one shoulder by crossing the chest [5] with a pocket for a cell phone. Its interaction principle is simple: by pulling one strap the user's mobile phone number is sent out to other devices nearby over a short-distance radio signal, and the numbers of the parties in communication range are received. Pulling a second strap allows sending a message to the group. This interaction method completely changes the conventional usage of a mobile phone in a group communication.

Schwarz et al. [6] investigate another alternative method for controlling a mobile phone. They consider using a cord as an input method by claiming it is more accessible and expressive than buttons[6]. The cord in comparison to the binary buttons has several advantages. In the first place, it offers larger surface where the interaction may take place. Second, a cord could potentially provide continuous input [6] in four dimensions — by twisting, bending, touching and pulling (see Figure 5). All of these actions are easy and simple. In addition, a cord supports interaction which does not require the user to look at the control and is unobtrusive. Possible combinations like twist and pull can support highly accurate navigation and selection [6] in menus.

In their user study Schwarz et al. [6] focused on finding the most appropriate combination of the three gestures — pull, twist and touch – for targeting (navigation to a target and selection of it [6]) in respect to the speed and accuracy. These three interaction methods were tested also separately. Twisting had the fastest time to navigate to the target and the lowest error rate. This result holds also in the case of increasing the number of targets. Pulling had significantly slower navigation times for more than four targets but still lower overshoot rate. Not surprisingly, the lack of tactile feedback when touching the cord lead to slow performance even with three targets and far higher error-rate.

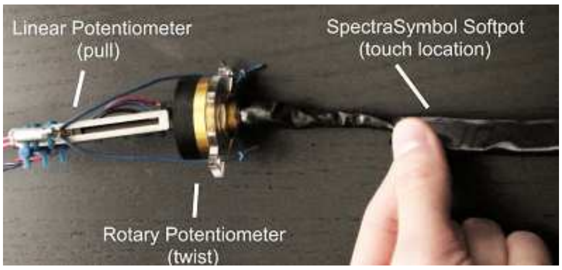


**Figure 5. Cord Input Prototype [6]**

Concerning the combination of the three gestures the outcome for "pull and twist" had the lowest success rate. This was basically due to the physical challenge of maintaining the tension in a cord while twisting [6]. The other two combinations had both success rates over 93 percent, where "twist and pull" is slightly better than "touch and pull".

Based on these results, Schwarz et al. give the following design recommendations [6]: twisting a cord is the most appropriate interaction with a cord for continuous input, while for selecting or toggling pull should be used. Future implementations for mobile devices that aim providing controls so that the given device is not pull out of a pocket or bag can definitely take advantage of these results as a cord can be easily integrated on the clothing or even wearable accessories as backpacks.

### *4.1.2 Output*

Concerning the output, a noteworthy outcome is the experiment results with the Spookies concept considering light feedback. For some of the toy units' thermochromic material, activated by a conductive high resistance layer on the back, was applied for the certain areas: eyes, different surface parts or the on/off button. This fabric employed color change as a feedback. The experiment shows that this is a too slow indication in comparison to the immediate feedback from diodes. However, diodes need special integration into the garment whereas the thermochromic fabric embeds the feedback into the material itself [4]. So which type of light feedback is used depends highly on the specificity of the given e-textile application.

During the investigation of the opportunity of a smart activity bag [8] Park et al. collected several interesting observations on what kind of passive interaction may be appreciated by users. Most users like the idea of using an integrated light as a reminder or for signaling. But they have concerns when a bag is in the closet or outside where it can be too bright so the light indication might not be recognized. Thus the integration of LED outdoors should be carefully examined. In addition, using vibration did not get a strong reception [8]. In the case of the smart bag, this kind of reminder is considered to be too late as it will be activated only when the bag is lifted up in the last minute before leaving. The most appreciated reminder method was a display with text notification instead of iconic that is assumed as too abstract indication for highly specific items.

Vibration feedback was studied also by Spelmezan et al. [18] who conducted an interesting user study on using vibrotactile motion instructions for snowboarding as part of the clothing. Vibrators were embedded in several places, and they would vibrate to indicate the wearer what part of his body was not well positioned. For example, if his right shoulder was too far forward, the vibrator in the shoulder would be activated to indicate the need of changing the position. Spelmezan et al. [18] found out that the location of the vibration motors can influence the interpretation of tactile cues [18] as the vibration over bones is more tangible than those over muscles. Second, the participants in the user study also had difficulties in determining the intended direction of the correction movement from the given tactile feedback. Perceiving the locations of the vibration was easy but suggesting whether to move towards or away from this position was not unified among the testers. So the decision was made based on subjective preferences.

The results of the listed two user studies about vibration feedback may be seen as a warning that it should be used carefully and that the perception of its meaning should be investigated before applying it into certain interaction pattern.

## 4.2 Mapping

As we have seen above with vibration as a feedback channel, mapping gestures and commands is not as straightforward as it would seem. The possible interaction gestures upon a garment or other wearable accessories differ quite a bit from the universal gestures when controlling given computational device that often have buttons or sliders. For example, the embroidered music balls [9] make use of physical hand gestures such as squeezing and stretching to perform and manipulate music.

The phone bag [3] of Holleis et al. also did not make use of a conventional mapping for the controls manipulating a mobile music player [3]. It uses touch sensitive areas that do not suppose button functionality as play/stop, forward/backward or volume up/volume down. Besides, these conductive surfaces are far more integrated in the design of the bag.

Holleis et al. helmet used a separation of the controls on the left and right side and hence separating the two functions: changing the track and manipulating the volume. The two touch areas were easy to find, clearly separated the functions and thus prevented unconscious mistakes.

Another research group [7] investigated which gestures can map certain control tasks for an audio device on wearable objects. Based on the number of identical appearances of a given gesture among the participants in the user study they created a list of representative gestures. For the "Play/Stop" operation users considered a single tap or touch on a prominent part of objects such as the center of the watch, the pendent of a necklace or the button on a hat [7]. Furthermore, gestures related to left movement or left side were associated to "Fast forward" and right movement or right side for "Fast backward". In addition, different participants used diverse directional patterns [7] for "Volume up" and "Volume down". Some of the gestures related to vertical, left-right, forward-backward or rotational movements [7]. This is a clear indication that further surveys should be considered in order to determine uniform mapping for these control. It is also worth mentioning that the symmetric placement for 'Previous title/Next title' and 'Volume up/Volume down' caused confusion among the testers [7].

The user study of Kim et al. [7] posed some additional issues that remain open, namely the need of special criteria to measure the representativeness of gestures, the need of refinement of a gestures set, the convenience of a gesture, as well as the suitability of certain clothing or object for a given interaction.

## 4.3 Challenges

As stated before, the field of wearable ubiquitous computing is still new and unexplored and there are several challenges that have to be addressed in respect of interaction. In the following subsections we briefly introduce them.

### *4.3.1 Social acceptability*

A major issue that should be considered is how and what people would want or accept [3] as type or way of interaction. Sometimes there is a need for a compromise between fashion and functionality. As the garment is part of the appearance of a person, the design of the controls on the fabric should be acceptable in the public as well as it should not be too outstanding in a way that the user will dislike. Certain areas or parts of the clothing are more preferred in respect to the social acceptability. Holleis et al. [3] found in their user studies that the upper (thigh) part of a trouser, the wrist band and a separate bag are well appreciated by users. They basically rejected neck, upper body, hips and sleeve as being comfortable or acceptable positions for the placement of controls. However, some users suggested the belt for integration of controls.

Concerning the layout and arrangement of the controls there are no clear expectations [3]. There is no definitive design that the majority of users will prefer. Holleis et al. found out that testers get easily used to a specific arrangement after a certain trial-and-error period [3].

### *4.3.2 Reachability*

A position of a control does not have to be only socially accepted, but also easily reachable. The factors of main importance for textile interfaces are the exact location and the way to identify certain controls among others Most of them should be tactile recognizable by the user as he or she very often operates without looking at the controls or during other activities such as sports, work, household activities, etc. If offered three different shapes of music player buttons (see Figure 6): visible, indistinguishable ornamental and invisible [3], users prefer the invisible ones because of their look. But during operation visible and ornamental ones have higher success rate. Therefore it is advisable that controls are both visible and tangible.


**Figure 6. Different styles of input buttons used in [3]**

The quick and simple finding of controls is influenced also by the body posture [3]. So the location should conform the body position when the interface is going to be used, e.g. while sitting, standing or moving. A possible solution that overcomes the different postures problem is to use detachable controls [3]. So it would make the location adjustable to the current body position. However, it has also the advantage that the controls are reusable while the original garment can be exchanged when worn out.

### 4.3.3 Look and feel

In the Spookies interface, for instance, all mechanical buttons and vibrating motors are hidden in the textile and only diodes are visible to the user. The toys are made of a knitted fabric and their color, pattern and relief are used to provide visual and tactile feedback about the different pairs or units [4].

The snowmobile suit for arctic conditions is exposed to other limitations that constraint the interface: i.e. the user should be able to operate with gloves because of the hostile arctic environment [5]. Moreover, the interface should be useful for both left- and right-handed people [5]. Additionally, as the suit is already heavy enough, the weight of the new interface is restricted in order to not cause inconvenience to the one wearing the suit. So the wearability and comfort should be preserved.

### 4.3.4 Wearable-object-based Interaction

A challenge for today's mobile devices is their continuously shrinking size. This limits the interaction surfaces and requires moving the controls to clothing or other wearable objects. Kim et al. [7] explored thirteen objects for controlling a mobile audio device. They focused on three operations: play/stop, fast forward/backward and volume up/down. It turned out that the watch and the earphone are the most preferred objects to use for these operations. A necklace, bracelet or belt had second lower preference. As most inappropriate interaction surfaces, users specified the following objects: shoes, pants, gloves. Intermediary preference was expressed concerning the ring, hat, glasses, bag and shirt. It is important to mention that many users had concerns about unintended activating of the controls due to unconscious gestures [7] as they are used to wearing these objects as part of the clothing not as a possible control to given device. Nevertheless, they appreciated the wearable-object-based gesture interface [7] as convenient as they do not need to take out the device and can continue their main activity. In certain cases, the interaction does not require visual attention and this can be seen as additional advantage. In concern to the social acceptability, users share the opinion that bystanders are unlikely to be aware [7] that they are actually controlling a music player.

## 4.4 Guidelines

We have seen before, there are several challenges and constraints to address when designing textile interfaces and certain guidelines exist to deal with them. These rules also apply to other types of interfaces. One of the most important is the requirement for one handed interaction. On one side, as the controls are placed on wearable garment, e.g. a wrist band or sleeve, this automatically makes impossible the operation by both hands. Sometimes it is quite hard to use both hands during certain activities like driving, jogging, working or cooking.

Another issue to be addressed is the need of immediate feedback. It is vital as users are used to the 'button-like click' feedback [3]. A missing quick response to their touch action will lead to repetition of their action, to use more force or to prolong their action. Tied to this immediate feedback issue is the fear of accidental activation [3]. Actions have to be registered quickly and a feedback must be provided as soon as possible, but false reading and accidental activation have to be thought of. If a sensor is too sensitive, actions can be initiated while they should not. A prolonged touch of the control may be used in order to prevent accidental activation, but the timing has to be right not to upset the user. Another solution is to use an activation area [3]. When a touch is detected on a control, another sensor can check if the palm touches an area just above the controls. The last option is to use controls with a fast response time and a key lock function to prevent unintended use.

Future implementations using gesture-based activation of controls should take into consideration the unconscious activation. Users wear their clothing or accessories as part of their fashion outfit. Using garment or wearable objects as a control is still not a natural matter and methods to avoid the accidental activations of these controls have to be studied deeper.

## 5. CONCLUSION

In this paper, we introduced our readers to the new research field known as textile interfaces. We showed how these textile interfaces could be beneficial to the educational world. Several studies [2], [10] have been conducted and point out how workshops on textile interfaces helped for increasing student engagement in new domains like computing and electronics, how they helped the diversity, by attracting female students to engineering fields, how they could reconnect arts and engineering by sewing and using electrical components and wiring as part of the aesthetic design.

This paper also revealed the main technological aspects of textile interfaces, by presenting the old and new challenges that had to be overcome, along with the advantages of these systems compared to other wearable computing systems. The hardware section was not meant to be a full account of what is available, but of what is possible, and showed innovative components like fabric PCB or piezoelectric materials.

Finally, the section on interaction presented the development of the kind of interactions that are possible, along with the challenges raised by these new textile interfaces and finally gave directions about how to develop the right kind of interaction for textile interfaces.

## 6. FUTURE WORK

Textile interfaces are still a brand new research topic. There is still a great deal of investigation and work to be done.

From the different studies [2], [10], [11] we based this report on, although some attempts have been made, like the BrickLayer [11], it is obvious that there is a need for "developing user-friendly programming languages and environments for working with e-textiles" [2]. It is crucial to develop more approachable programming tools in order to lower the entry threshold and allow more non computer scientists to explore the field of textile interfaces.

Also, the different construction toolkits available at the moment lack interoperability [10]. For example, the Lilypad uses conductive threads to link its components, while the Elektex uses plastic socket and pin connectors, and the Teeboard uses metal snap fasteners [10]. This richness of connectivity prevents users from interchanging components from these toolkits.

As we have seen, fabric PCBs are a great improvement over their classic counterpart. Now, the focus could be moved to other components like resistors and finding ways to replace them by a fabric equivalent [9].

On the interaction part, more user studies have to be conducted in regard to social acceptability and ease of use.

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