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## **Prototyping of a communicating textile<sup>★</sup>**

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### **Résumé**

A new era is coming with intelligent materials, which are able to provide diverse functionalities to users all along the product lifecycle, during the design, manufacturing, use and dismantling phases. These materials can track their own evolution all along the Supply Chain, which lead to gather helpful information and allow information continuum at all time and everywhere (synchronization of informational and physical flows). Usually, these functionalities are fulfilled via the integration of specific electronic components into the material (wireless sensors, RFID). The present paper forms part of this framework. To go further in the interpretation of this paradigm, it proposes an approach to design this kind of communicating material and its necessary communication architecture useful to enable communication between textile and environment. Feasibility studies related to industrial processes, to usage and technology constraints are handled within the paper too. A prototype is realized in which a huge number of tags are scattered. Afterwards, the physical limits of the textile are evaluated and compared to a classic one. A digitizing tool is also introduced which allows getting dynamically the the location map of tags constituting the material.

*Key words:* Communicating material, Prototyping, Smart clothing, Supply chain management, Ubiquitous computing.

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### **1 Introduction**

A new era is coming with intelligent materials, which are able to provide diverse functionalities to users all along the product lifecycle, during the use phase (medical sector [6, 3], clothing [26], military [22], home automation [12, 2], ...) or during the design, manufacturing and dismantling phases. These materials can track their own evolution all along the Supply Chain, which lead to gather helpful information and allow information continuum at all time and everywhere. As a matter of fact, [5] showed the product needs technologies not only to carry data but both data and knowledge (e.g via wireless sensors, RFID, ...). Both physical and informational flows being merged into the product, that kind of material ensure a synchronization between them [23]. Works about *intelligent products* [30, 20] in the logistic field often consider discrete products. In this context, each product disposes of a distinct informational part, located on an electronic tag. Nonetheless, this concept already shows a certain number of limits : discrete reading, risk of tag damage, problem of information loss when cutting the product in several parts. [27] emphasizes the significant proportion of defective tags and false reads (which has been as high as 20 – 50% in some pilot projects). The problems pointed out previously could be resolved, if one imagines that all the material composing the product has the property to be communicating. The technology is inserted into the material during its initial production so as to be inseparable. Then, it is not a punctual part of the

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★. This paper was not presented at any other revue. Corresponding author S. Kubler.

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product which acquires and broadcasts information but the material in its wholeness. The product becomes ipso facto communicating inherently, and reading information is possible anywhere on the product (not only via the RFID tag), enabling copy/redundance/backup information solutions. The idea of a communicating material has been introduced and discussed for the first time in our previous paper [16].

The relevance of implementing this concept is argued (at least qualitatively) in our previous paper, too, with a study made over different case studies through literature, each one focusing on a specific phase of the product lifecycle. Next, a generic functional analysis is carried out in the same paper to highlight functionalities of the communicating material. According to the possible current technologies, a list of addressed technological and scientific issues is expressed, classified in four clusters :

- **Material instrumentation** : it is mainly composed of issues related to the achievement of the communicating material in its natural state. It concerns choices about tag density, tags and RFID readers to implement or still the integration of "tag systems" into a fibrous composite or into a textile. The encountered problems in this cluster are principally problems of choice of solution with respect to the technological constraints.
- **communication architecture** : the aim is to develop a middleware allowing to exploit the physical layer (composed of tags and readers). More specifically, it addresses issues like the accessibility of material, the tags order to read/write, . . .
- **data dissemination** : the purpose is to develop an embedded information system within the material, able to offer some services expected by users involved in the life cycle. In order to implement this information system, it is necessary to define the data model supporting the exchanged information throughout its life cycle and to address some issues related to data allocation, availability and consistency in mobile environments [19].
- **data completeness** : This cluster focuses specifically on issues concerning data completeness. Active products such a communicating materials have limited characteristics (small memory, infrequent communications, . . .), leading to issues regarding data summarization in mobile environment systems [11]

The present paper's aim is to propose an approach to build a communicating textile prototype and to bring elements of solution about some of these issues, especially related to the material instrumentation by taking into account diverse constraints specific to the studied system. The paper fits the improvement of product traceability as stated previously, but also intelligent material framework and particularly *e*-textiles. In recent years, several projects have been focused on similar research topics, let us notice the project *MERMOTH* that contributed to Medical Remote Monitoring of clothes from 2003 to 2006, the *OFSETH* project (Optical fibre sensors embedded into technical Textile for Healthcare) from 2006 to 2010 or still *ProeTEX*, focusing on *e*-textiles for firefighters and civilian victims monitoring. Moreover, numerous projects are coming up, such as the next *CALL FP7*, which has a topic called *SFIT* (Smart Fabrics and Interactive Textiles), whose aim is to expose interests to develop new functionalized textile materials, or *ISIS* (society hosted by the University of Bremen) which is currently working on sensory materials. Thus, one can easily see that giving enhanced functionalities to materials is a hot topic today, which seems to be promised to important research opportunities. As a matter of course, this concept involves a need in miniaturization of components in order to give the material this ability to be intrinsically communicating and seamlessly, this point meets the vision of *Smart Dust*<sup>1</sup> described in [14]. Although we are still far from the realization of this vision, there are already devices available that measure less than 1 cubic millimeter.

To design such a material, a guideline has to be followed. The figure 1 highlights the different steps to design, to produce, to test and to use a communicating material and more specifically in this paper, a textile material prototype. Except for the section 2 which focuses on establishing a state of the art about intelligent materials, all the sections of this paper are organized regarding these steps, where each step is described for our prototype. The first step aim (see figure 1), in designing such a material, is to conduct a functional analysis of the scenario requirements to specify functionalities which have to be provided by the prototype. The second step concerns the characterization of the used technology in order to take into account its limits for the prototyping. In our case, we focus on maximal tag density which is the subject of the section 4. Afterwards, several processes allowing scattering tags into the material have to be studied in order to take into account the characterization done in the previous step. This step corresponds to the section 5. As a matter of course, it is necessary to study the quality of the designed material (usage constraints, . . .), this step may be based on standard tests as done in section 6, regarding *OSI* standards in the textile framework. Finally, an architecture of communication and new tools have to be developed (according to user requirements) to enable the material to communicate with its ambient environment and vice-versa. One solution is proposed in the last section, where a digitizing tool is introduced.

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1. Definition given in [14] : The vision of *Smart Dust* is to be able to implement computing devices the size of a grain of sand that will contain sensors, computational power and be able to communicate wirelessly with other devices.

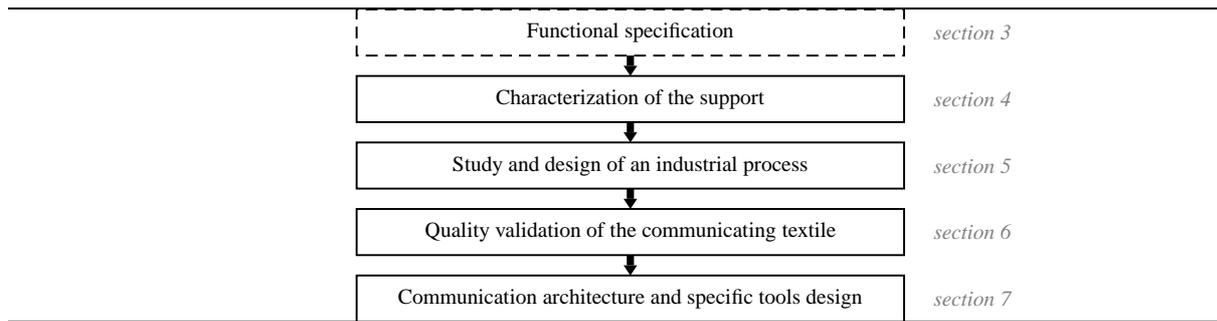


FIGURE 1. A guideline to build a communicating material

## 2 Related works about intelligent materials

### 2.1 Introduction

Various materials are called *intelligent*. In reality, these are materials able to communicate with their ambient environment or from time to time, able to act according to solicitations from their environment so as to fulfill the user requirements or their objective function. They may have diverse functions but the main one is to answer to stimuli perceived. The *i-Bar* is a representative example [1], which reacts to all objects in contact with. Intelligent materials could possibly interact with daily devices. Let us consider the example of a washing machine that would automatically interrogate tags embedded in our clothes and adjust the wash cycle accordingly [18], or health monitoring and assistance thanks to clothes. In this case, clothes would be able to dissociate any part of the human body and in a result, act where necessary (indeed clothes and textiles are in direct contact with about 90% of the skin surface [4]). A last case concerns communicating or intelligent walls as pointed out by [7], who said : *the walls could have ears and these walls could talk*. Thereby, predictive maintenance could be implemented so as to warn about possible problems (crack, heat loss, ...). In the *Internet of things* paradigm, increasingly, connections are not just people-people or people-computers, but between people-things and most strikingly, things-things [18]. The idea of a communicating material is really close to concepts such as Ambient Intelligence and Ubiquitous/Pervasive Computing [29, 25].

The majority of intelligent materials owns an electronic part, i.e an external entity grafted on the material initially inert in order to give functionalities (e.g a RFID tag on a wood plank or a microprocessor embedded into textile). However, it also exists materials devoid of electronics which may be considered like intelligent regarding their chemical composition. Let us mention materials which are endowed of reaction abilities, transformation, through mechanical rules, electrical, ... Let us notice the followed categories : *piezoelectric, electrostriction, magnetostriction, shape memory alloy*). The microencapsulation may be also considered as an intelligent technology, which allows to encapsulate products which can be medicines, essential oil or still perfumes [13]. Then, these capsules liberate progressively their products according to the context.

### 2.2 e-textiles

One of intelligent material categories is the textile in which various electronic components are grafted (sensors, microencapsulation, ...), called *e-textile*. Both main sectors developed about this topic are clothing and medical [24, 10]. Usually, textiles are classified into two categories according to two kinds of design. The first is the creation of copper wired network or other conductor metals on which several components are grafted. This technology enables to use high power components, but raises some drawbacks, e.g related to textile design whose rigidity is uncomfortable from a user point of view [17]. The big deal considering such a technology is the breaking of electrical threads which causes the integral destruction of the prototype. Regarding to the second technology, components designing within flexible materials such as optical fiber, carbon nanofiber, piezoelectric materials preserve textile comfort, lightness and softness. Considering the choice made in regards to materials but also in regards to our goal (which is to scatter information into the textile material), our prototype implements that last technology. However, to date, this choice engenders limited functionalities and power. [21] chose this approach to build an *e-textile* where the thinness of the integrated sensors made invisible those components to the person wearing this outfit. Nonetheless, the barrier separating both categories is narrowing. [15] integrates more powerful components, while keeping textile softness. [9] shows that it is possible to have an aesthetic insertion of several components.

The CEA-Léti company (from France) proposed a special technology which allows to graft RFID tags on a flexible polymer thread (project "Diabolo") [8]. However, this technology is still in prototype stages and is not available "on the shelf". That is why, we opted for the RFID technology developed by Hitachi ( $\mu$ chip), working in MF range and which is currently the smallest on the market ( $0,4 \times 0,4 \times 0,1mm$ ) [28]. The paper aim is to highlight how to design and build a material able to communicate, to send and receive information while using this type of RFID. For our purpose, the second category of *e*-textile stated previously is considered. Information exchanged from the communicating material to its ambient environment will be information related to the product traceability or the daily usages, . . . Let us remember that in our case, the material specificity is to acquire and broadcast information in its wholeness. Thus, the product becomes ipso facto communicating inherently, and reading information is possible anywhere on the product. The next section described the first step of the guideline mentioned on the figure 1, related to the functional analysis.

### 3 Functional specification of the communicating textile

First of all, it is necessary to conduct a functional analysis of the scenario requirements in order to specify functionalities which have to be provided by the prototype. In our case, one part of the global analysis was carried out in our previous paper. The main objectives of the present paper are to study the feasibility of such an *e*-textile, according to several constraints :

- *interference constraints* : the use of specific components such as Hitachi RFID technology involves to determine some of their properties such as the reading zone (zone in which a tag and a RFID reader can communicate), which will constraint the design process.
- *manufacturing constraints* : For manufacturing sake, it is necessary to find industrial processes compatible with our communicating textile,
- *usage constraints* : to validate the textile quality, it is necessary to assess the physical limits of the prototype,
- *communication constraints* : the prototype must communicate with its ambient environment,

The next section focuses on characterizing the used technology in order to take into account its limits for the prototyping.

### 4 Characterization of the support of communication

#### 4.1 Characterization of the Hitachi technology

The Hitachi technology is still limited on some points. Firstly, it is impossible to store information directly into tags (read only technology), so it is necessary to implement a database within the network architecture. Secondly, one of the main problem is that it does not exist anti-collision protocol for reading tags. In spite of these limits, everything seems to suggest that future technologic improvements will overcome these problems. However for now, it is necessary to characterize correctly this technology for building the prototype.

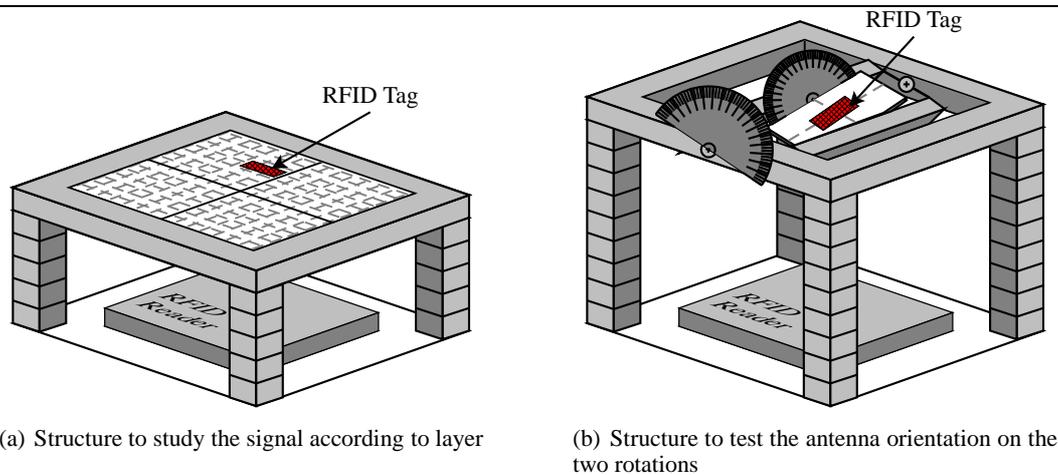


FIGURE 2. Structures implemented to study the *reading zone* (zone in which a tag and a RFID reader can communicate)

Various experiments are led with the intention to specify the technology. First of all, it is necessary to study the reading zone since the tag repartition into the material depends of that. Indeed, this technology does not have an

anti-collision protocol and two tags can not be present in the reading zone at the same time. In order to do that, two structures are designed figure 2 allowing to study the signal shape, layer by layer according to the antenna orientation. The first structure figure 2(a) consists of a RFID reader which stands upon a basis and positioned against two abutments and four columns adjustable in height. Upon these columns stands a graduated plate where the tag is positioned. Thus, we go all over the grid (millimeter by millimeter) in order to know where the signal is lost. The second structure, shown figure 2(b), enables to test the antenna orientation on the two rotations.

Thus, the reading zone is modeled in 3D for each height, according to the antenna. The figure 3(a) illustrates this shape for a specific height and a specific angle. Overall, considering 8 angles and 10 heights, 160 zones are obtained. The *excluded* cylinder is modeled (encompassing all points from the shape) figure 3(a) with the aim of simplifying the analysis. As a matter of fact, the signal shape is peculiar to the used *Hitachi* technology. For instance, the *Omron* technology has been considered in another framework and the shape is similar to a semi-sphere. Finally, a synthesis of all cylinders is realized. The cylinder radius are drawn in the figure 3(b) according to angles and heights of the tag, regarding to the reader. On the one hand, we observe that the signal varies in function of the antenna axis and on the other hand, the farther the tag is from the reader, the larger the dispersion is. Conversely, there is a common diameter of the signal to the origin.

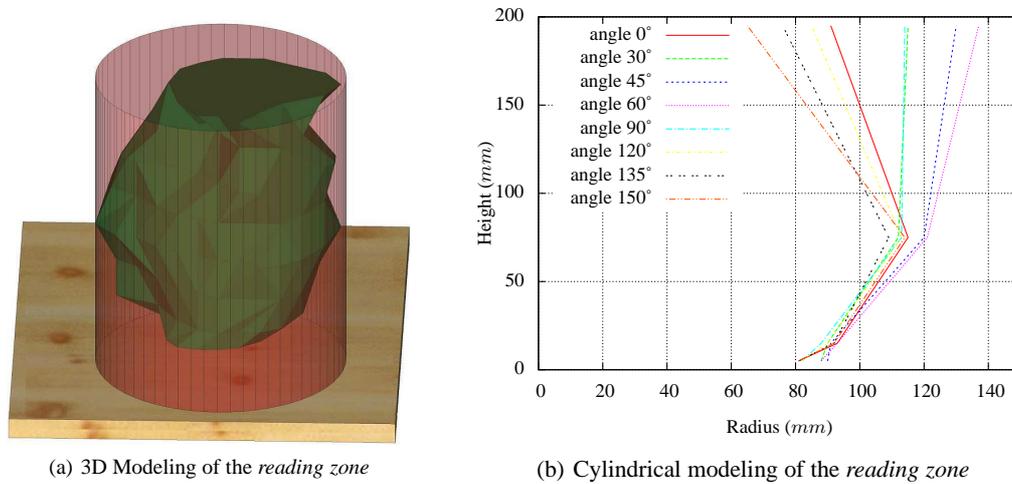


FIGURE 3. Study of the *reading zone* (zone in which a tag and a RFID reader can communicate)

#### 4.2 Analysis

The maximal density of tags found is function of the antenna orientation and the kind of reader. Then, it is possible to integrate  $\mu$ chip *Hitachi* into the material with a maximal density of  $150\text{mm}$  between tags by using the technology basically and  $26\text{mm}$  thanks to a reader developed by ourself (we removed the reader amplifier), i.e in total  $49\text{tags}/\text{m}^2$  and  $1521\text{tags}/\text{m}^2$  respectively. Obviously, some interferences could prevent the good reading of tags. In a result, methods have to be developed to assure a sufficient redundancy of information (according to priorities and requirements).

### 5 Study and design of an industrial process

The prototype has been elaborated in collaboration with the CETELOR company (textile test center : France), which is specialized in Research & Development for industrial companies and is licensed COFRAC ISO 17 025.

#### 5.1 Choice of the textile process

Several processes allowing to scatter tags into the material have been studied. In order to do that, it is necessary to take into account the material characteristics, namely that tags do not support heats exceeding  $100^\circ\text{C}$ , thus processes which implement infrared heating mechanisms are prohibited. Along the same lines, woven textile processes can not be used since a mass called reed comes regularly hitting the textile in order to tie threads together, and thereby could destroy embedded tags. In the same way, manufacturing processes making non-woven textile usually include operations such as cleaning and opening fibers made by reed cylinders or by compressed air. Moreover,

these processes generally carry out mechanical needlepunching<sup>2</sup> or hydroentangling<sup>3</sup> operations, which would destroy antenna of tags. The last considered solution to scatter tags is based on a thermo-bonding process of two textiles, this process implements neither mechanisms causing shocks, nor too hot processes (the set of tags does not undergo the temperature) and the tightening pressure does not turn out to be a problem.

### 5.2 Building the communicating textile by using a thermo-bonding process

Two kinds of textile have to be selected to realize the thermo-bonding process. The first chosen is a non-woven hydroentangled textile (polyester of  $50g/m^2$ ). The second is a woven textile by reason of its high resistance to efforts (plain weave of  $123g/m^2$ ). The manufacturing process is illustrated figure 4, where the woven textile is pasted by one engraved cylinder before being pressed against the second textile, i.e the polyester. Finally, a test showed that 100% of tags embedded into the material were usable.

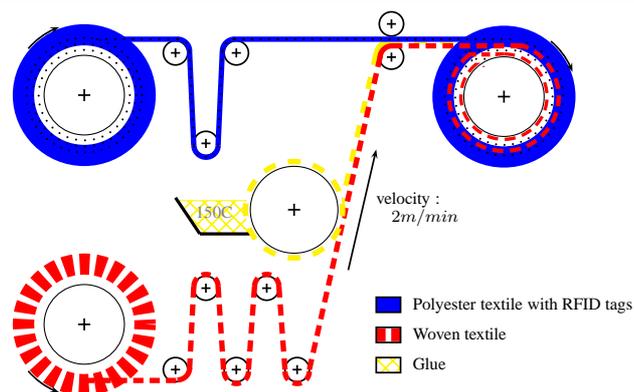


FIGURE 4. Thermo-bonding process for integrating  $\mu$ tags into the textile

### 5.3 Analysis

Two observations can be made, one related to visual aspect (see figure 5) and the other one related to the touch. Firstly, it is possible to see some tags through the textile, which damages the aesthetic quality. However, this problem may be overcome quickly enough thanks to a more judicious material choice. Secondly, it is possible to feel the extra thickness caused by the insertion of tags, but this one is insignificant. The textile rigidity is also increased which comes directly from the antenna, and damages the softness quality. Nevertheless, in the same way as [21], the elaborated prototype does not engender problems about the user comfort. The present prototype disposes of a small information capacity and by this fact, a contradiction exists to date : the augmentation of the memory capacity (i.e the density of tags) will reduce the user comfort and vice-versa. In spite of that, we may assume that technologies such as *diabolo* will overcome this problem.

## 6 Quality validation of the communicating textile

Three laboratory tests have been conducted to know the physical limits of the prototype. We defined applications in the clothing industry. These tests have been done in the CETELOR laboratory under controlled atmosphere at  $20C \pm 2C$  and  $65\% \pm 5\%$  of relative humidity. The test tubes, once cut off, stayed 48h to stabilize.

**Resistance to washing** The first test studies the communicating textile behavior when undergoing a hand-wash cycle (NF EN ISO 6 330/A1 and NF EN ISO 3 759 standards). This simulation deals also with chemical treatments met either in the industry (strikethrough, coating) or at home (repeated washing,...). Every test tube is tested according to the following cycle :

- 3 phases of washing,
- 3 successive phases of draining and rinsing,
- 1 phase of rinsing again,
- 1 drying using air.

2. *Needlepunching* : Mechanically binding a web to form a fabric by penetrating the web with an array of barbed needles that carry tufts of the web's own fibers in a vertical direction through the web.

3. *Hydroentangling* : Process for forming a fabric by mechanically wrapping and knotting fibers in a web through the use of high-velocity jets or curtains of water.

After the test, a control shows that all tags are functioning. Concerning textile alterations, it is to be noted that the shrinkage of the non-woven part compared to the woven one leads to important mechanical constraints causing the two to peel off more specifically around each inserted tag. These last ones thus generate critical spots. The Table 1 summarizes these results.

TABLE 1  
Synthesis of the results from tests performed on the textile prototype

Performed Tag test	Tag presence	Test tube number	Noticed damage	First degradation	Number of cycles	Signal range
Washing	Yes	1	Small unsticking of a few millimeters in the corners, unsticking between the textile and the tag, shrinkage of 1cm	/	1	195mm
	No	2	Small unsticking in the corners going to several cms, shrinkage of 1cm	/	1	/
abrasion	Yes	3	Apparition of two holes around the superposition of the two antennas and the tag, causing thereafter textile wrenching	15 000	20 000	195mm
	Yes	4	Apparition of one hole of a few centimeters around the tag	15 000	20 000	195mm
	No	5	Apparition of holes of a few millimeters at several spots in the textile	20 000	20 000	/
	No	6	Apparition of holes reaching one centimeter at several spots in the textile	22 000	24 000	/
flexion - traction	Yes	7	No alteration	/	80 000	195mm
	Yes	8	Small unsticking between the textile and tag	40 000	50 000	0mm
	No	9	No alteration	/	80 000	/
	No	10	No alteration	/	80 000	/

**Resistance to abrasion** This second test measures the impact of friction on our prototype. To design this test, the NF EN ISO 12 947 – 2 standard has been used and adapted, to fit our sample size. The figure 5(a) illustrates the mechanism implemented, needed for the experiment. The mobile part puts a pressure of 9kPa on the textile and follows a *Lissajous* curve. This time again, tags generate a faster textile degradation (see Table 1). First degradations appear before 15 000 cycles with holes smaller than one millimeter in diameter, because of the extra thickness due to tags, which increase the abrasion effect. The figure 5(b) shows the degradation obtained after 20 000 cycles, where the hole and the tag can be seen.



(a) Abrasion (NF EN ISO 12947 – 2 standard)

(b) Visibility of one tag after abrasion

FIGURE 5. Communicating material built by a thermo-bonding process of two textiles, subjected to abrasion tests

**Resistance to torsion/bending** This last laboratory test consists in measuring the resistance of the whole textile to torsion and bending (NF EN ISO 7 854). This cyclic repetition produces an early fatigue of the RFID tags. Test tubes are first tested every 1 000 cycles during the first 5 000 cycles to simulate fast degradation, and every 5 000 cycles between 5 000 and 40 000 cycles. All tags have the same orientation so that the force undergone by each

tag is the same. No important fatigue sign is recorded, the only denoted alteration is the destruction of one tag that happened before 40 000 cycles.

The results of these three tests related to usage constraints performed on the textile prototype are summarized Table 1. It shows that the textile choice is important, since the textile resistance depends on these last one. The presence of tags into the textile generates critical spots ; however the textile is not too weakened compared to a classic one (without inserted tags).

## 7 Communication architecture and specific tools design

### 7.1 Global communication architecture

As a matter of course, after building the communicating material, it is necessary to develop the communication architecture to enable communication between textile and environment. The global architecture implemented is illustrated figure 6, it employs a communicating material, this material is read by a set of RFID readers.

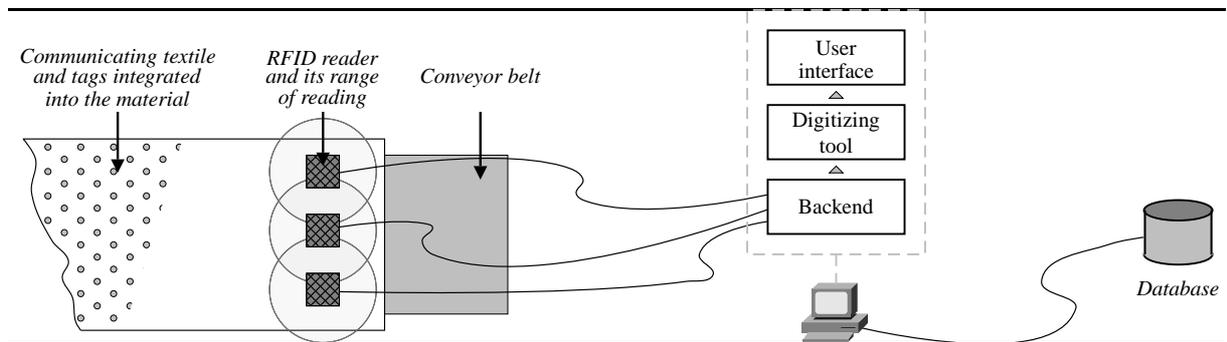


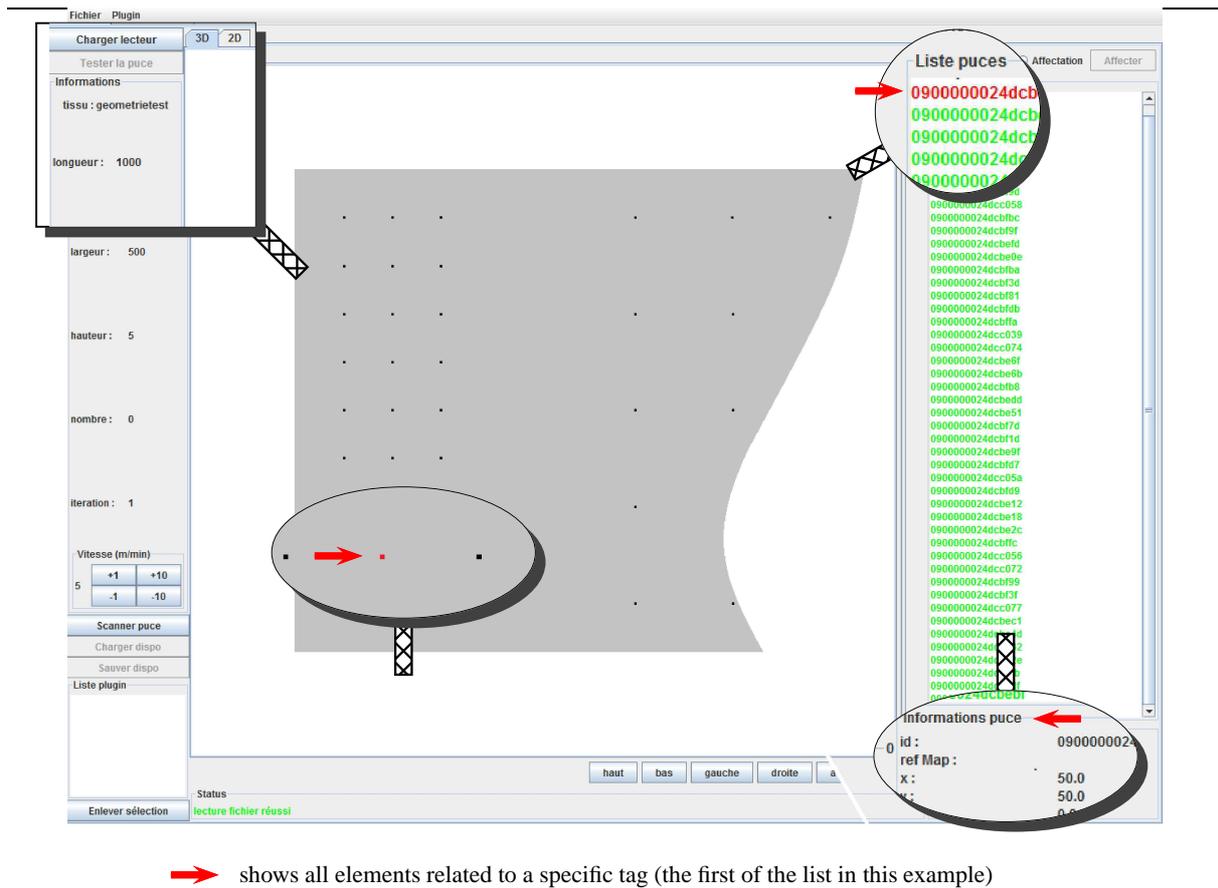
FIGURE 6. Global communication architecture implemented for the communicating material

Each reader generates events if tags are detected within its reading zone. The set of readers are controlled by a generic *backend* component which is in charge of collecting RFID events and giving them to a specific tool, called *digitizing tool* introduced in the next section. This tool allows digitizing the material, i.e it builds dynamically the location map of tags constituting the material by relying on RFID events. Thereby, information related to specific areas of the material are stored into a remote database. An user interface is implemented to display this map, a screenshot of the main interface is shown figure 7.

### 7.2 Digitizing tool

All information concerning the material is modeled as a virtual map and store in the database. The aim of the digitizing tool is to compute dynamically the position of each tag into the communicating material and to report it on the map in the database, with the tag identifier. When a data is stored in the database, it is automatically associated with one or more tags, which allows later determining the position of the data on the communicating material. For instance in the framework of textile manufacturing, it could be interesting to report textile flaws (holes, snags) on the virtual map. Later, if the textile is cut in sub-pieces during the manufacturing process, this information could be used to verify that all sub-pieces are free of flaws. To calculate the location of tags, the implemented algorithm relies on the set of events and especially on the following parameters : {tag identifier, reader identifier, acquisition date}. Moreover, since the reading zone (between a *Hitachi* RFID tag and its reader) has been defined as a cylinder in section 4, a method based on the chord of circle is used to calculate the tag position. This tool is compatible with several RFID technologies by taking into account the reading zone peculiar to each of them (e.g Omron, Hitachi). Moreover, the user can add the RFID technology he wants, after having characterized this one, as done in section 4 and determined the reading zone shape. This paper does not present the different algorithm steps but briefly describes its results.

The software tool allows to switch between *2D* and *3D* modes according to user requirements, i.e either in order to see the product in its wholeness or one layer of this one. The figure 7 shows the tag repartition into the textile through this software. We can observe on the left information about textile dimensions, at the center the *2D* view of the textile where dots correspond to tag positions, on the right the list of identifiers related to detected tags and at the bottom right information about tag location into the material. Let us notice it is possible to select one tag among all, which is highlighted in red color (in the *2D* view and the list).



→ shows all elements related to a specific tag (the first of the list in this example)

FIGURE 7. Screenshot : *digitizing tool* of the material : allows getting dynamically the the location map of tags

## 8 Conclusion

This paper fits the concept of intelligent materials and is especially related with the *e*-textile domain. These materials propose functionalities to the different actors during all their lifecycle via specific components (RFID tags, wireless sensors, ...). Several works in the literature are stated regarding domains such as health monitoring, home automation, daily activities, ... Increasingly then, connections are not just people-people or people-computers, but between people-things and most strikingly, things-things. In this paper, a guideline to build a communicating textile (constituted by a huge number of  $\mu$ tags) is proposed. Indeed, each step to design such a textile is described : in a first time a study about the characterization of the support of communication is led, next an industrial process is implemented to build the communicating textile, after that, the prototype is tested in order to assess its limits and at the end, an architecture of communication with a specific tool is developed. In particular, a *digitizing tool* is elaborated so as to determine dynamically the location map of tags constituting the material. Thus, it is possible to fulfill diverse functionalities such as identify specific tags and allocate information related to a specific area.

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