FACILITATING USER INVOLVEMENT IN DEVELOPMENT OF 3D SMART TEXTILES FOR HEALTHCARE APPLICATIONS

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ABSTRACT

Smart textiles is a rapidly growing area in which new materials and technologies provide textiles with characteristics of interest in healthcare, such as textile electrodes to capture (electro)physiological signals from the heart (ECG) and brain (EEG) or sensors for respiration monitoring. Typically these textiles consist of a combination of various materials which most often form a 3D structure.

In order to take full advantage of these new opportunities, different disciplines need to come together in the development of new innovative 3D smart textile products. One strong and valuable contribution to this is to involve users early in the development process.
This paper focus on how product representations, e.g. textile prototypes or material samples, can facilitate the communication and collaboration between users and developers in the development of new healthcare solutions based on 3D textiles. This paper describes how product representations support the exchange of knowledge and experiences between users and developers by acting in five different facilitating roles; demonstrating, verbalizing, visualizing, stimulating and integrating.

Keywords: Smart textile, 3D weaving, product representations, user-centered development

1. Introduction

Today new technology gives us unprecedented opportunities to develop textiles in a way that were not possible earlier. New textiles with complex structures can be developed with new techniques and new materials. Smart textiles, i.e. textiles based on new “smart” materials and/or textiles which have the possibility to sense and react to stimuli from the surrounding environment, can be used to develop “smart” applications to meet demands in healthcare e.g. to monitor (electro)physiological signals using textile electrodes/sensors [1]. Another textile technique is the three-dimensional (3D) textiles which is a category of technical textile that recently has been successfully applied in healthcare. This is demonstrated by e.g. dressings for advanced wound healing, bandages, textile blood vessels, grafts and scaffolds used for growing new tissues [2]. However, new opportunities also entail new challenges. New complex constellations, consisting of various disciplines e.g. health care, electronics and textile engineering, will be required to work closely together and different knowledge has to emerge and be developed into new, shared knowledge in order to develop new textile products. Thus, in order to take full advantage of the new opportunities the textile industry needs to find new ways to develop new, smart textile-based products.

One strong and valuable contribution to the development of new innovative products is to involve users as early as possible in the development process. Research has shown that users often modify or even redesign new products and equipment so that these suit their needs and requirements in a more accurate way [3]. According to von Hippel [4] as many as 40% of users make modifications to the design of the product they buy in order for it to better suit their needs. The development of technical innovations must hence take a broader approach and develop new, innovative products from a user perspective [5]. By including healthcare personnel as users in the development of new textile products directed to the healthcare market, completely new solutions or applications may be suggested based on the users' experiences and what they see is lacking in their everyday work situation. However, such user involvement may face several barriers.

One barrier is attitude and beliefs that users can or cannot contribute. Even though users have been found to be able contribute with input already early in the development process [4-6], their involvement is often limited to acting as informants or evaluators of already designed solutions. Another barrier is the communication cross borders in multidisciplinary teams [7-8]. The challenges faced include the lack of a common language and terms as well as an understanding for one another's skills and contributions to the process [9-11]. Söderman [12] claims that it is particularly important to establish good communication and mutual understanding during the early stages of a development project to allow an exchange of ideas to take place between users and developers. In order to have a broader approach to technical development it is essential to convert knowledge from one area of expertise into information which is comprehensible to someone with other experiences and skills, and hereby make the knowledge valuable to someone with a different background or who views the problem from a different perspective. It is crucial to support an extensive integration of different types of knowledge and skills to take the full advantage of the possible contributions of various disciplines.

Nevertheless, even if the user is represented in the process certain obstacles to identify the users' needs and requirements for the design of the product must be acknowledged. Some needs and requirements may be easy to identify and explained, referred to as captured requirements [11] as the users are aware of, and are able to verbalize them for instance during interviews. Other aspects have proven more difficult to identify and describe. 'Elicited requirements' [11] refers to requirements that entail a certain effort before they are possible to be communicated since the users may not (any longer) be aware of existing problems, as they consider the problem to be solved through their own modification of existing solutions. The most challenging are the 'emerging requirements' [11] which are very difficult for users to communicate as a result of them not being aware of existing potential design solutions until they have been visualized and tested [11; 13].

In order to overcome the challenges and facilitate the innovation and development process there is a need to support information exchange crosses borders. To generate the necessary and essentially new, shared knowledge across disciplines, researchers have argued the importance of utilizing different kinds of mediating tools, which can be used as a *lingua franca* by all team members in order to exchange experiences and gain new knowledge [7; 10; 12-15]. Product representations are a mediating tool that can be used to identify problems and needs, confirm that the problem has been correctly understood and interpreted by all those involved, and further elicit potential solutions [10; 13; 16-18]. They can also function as an instrument for clarification between disciplines and individuals, and decrease the level of uncertainty, which may exist when new solutions are to be identified and designed. Monö [19] describes the mediating role of product representations as follows; they may help the user and developer to recognize and evaluate different phenomena, elicit ideas and images to facilitate comprehension of different scenarios in the process, and stimulate feelings and impulses, resulting in individuals coming up with new thoughts and ideas. However, the product representation used must be chosen with care in relation to its purpose, as stressed by Hounde and Hill [20], as well as by Söderman [12] and Engelbrektsson [13]. This paper is a summary of a study on how to facilitate the involvement of the user in early innovation development [21].

2. Aim

This paper describes a case study where a multidisciplinary team, consisting of users and developers, gathered to explore the possibilities to solve a biomedical engineering problem using textile techniques. The purpose of the study presented in this paper was to examine how textile product representations, such as prototypes or material samples, can be used early in the development process to facilitate communication and collaboration between developers and users in the development process of a new textile product for healthcare.

The aim of this paper is to highlight how textile product representations can contribute to communication and understanding within a group of users and developers and the facilitating roles the product representations might have in the development of new textile-based innovations within healthcare.

3. The case

Long-term monitoring of brain activity (EEG) of premature infants is at present carried out as a requisite routine in the treatment of these vulnerable patients. Today's standard method is to position a set of electrodes in a certain order, according to the international ten-twenty system [22]. The positioning of the electrodes is a complicated and time-consuming process which requires specially trained staff. Another complication is that when the electrodes, placed one by one, eventually are in place, there is a risk that they will move out of position as the infant moves its head. This may disturb the measurements. There are different textile "cap" or "helmet" solutions available with integrated electrodes that considerably simplify the application of electrodes to the patient's head. However, the healthcare professionals have identified difficulties in executing long-term monitoring using these types of "caps" or "helmets" as it often results in complications in terms of pressure damage to the skin on the infant's head. Together, these problems result in that long-term recordings can only be implemented for a limited time and not according to what are the clinically motivated 24/7 EEG measurements.

3.1 The team

A multidisciplinary team was gathered to explore the possibility of using textile technology to solve the problem. The multidisciplinary team comprised of a neurophysiologist (a clinical EEG expert, specializing in premature infants), two biomedical engineers (one with expertise in signal processing and one specialist in long-term monitoring of electrophysiological signals), and two textile specialists (one in three-dimensional weaving and one in smart textiles engineering). The team may be identified as a group of individuals with different expertise gathered to examine a biomedical engineering problem. However, in this study the team was divided in two groups, representing the 'users' of the forthcoming product and the 'developers' of the same. The users are represented by the healthcare specialists and the signal processing specialist, while the developers are represented by the textile competences and the specialist in long term monitoring of electrophysiological signals.

3.2 Conceivable solution

Initially the healthcare professionals specified requirements that a potential solution needed to fulfil, such as; a soft cap or similar, including the required number of electrodes (~20); easy to apply to the patient; possible to use for uninterrupted measurements over a prolonged period; as well as avoiding the use of contact gel since it may irritate the patient’s skin.

A wide range of textile materials and manufacturing techniques allows the design of soft and smooth textile systems. In this project, with consideration to the healthcare professionals’ initial requirements, a recently developed 3D weaving technique was identified as a potential solution to the problem. The 3D weaving technique is predicted to ensure a light pressure to keep the electrodes in place while providing the necessary skin contact but without causing the damage that today’s method does. The 3D technique also presents an opportunity to manufacture an electrode system, including all of the required components, in one single process, joined together so as to make the electrodes easy to apply, increase the stability of the device and decrease the likelihood disturbances due to the patient’s movements repositioning the device on the head.

4. Research approach

The study covers nine meetings, (more or less) evenly distributed over nine months where the team met to develop the new textile solution to long-term monitoring of EEG signals. The meetings comprised of discussions concerning issues such as user requirements as well as technical requirements and opportunities, which informed the developers’ further development of prototypes between meetings. In this iterative process, new ideas or solutions could be prepared and tried out in order to be presented and discussed at the next meeting. In between meetings, the prototypes were tested by the users and the results were further evaluated and discussed at the next meeting. The results were analyzed both from the users’ and the developers’ perspective and formed the basis for the next development loop of the product representation in the iterative process. Decisions on how to proceed were jointly taken by both the users and the developers.

4.1 The product representations

Most of the representations used in the project were various textile artefacts, produced experimentally and conceptually in the iterative process. However, other representations were also used, including sketches of various kinds or commercially available products that offered properties, which were searched for or that were to be avoided.

4.2 Data collection and analysis

The analysis is based on participatory observations (by 1st and 2nd authors) during the team's project meetings and the development process of the textile solution. All but the first two meetings were recorded, using a smart phone equipped with an external microphone. The recordings were transcribed in full, and a qualitative content analysis was carried out [cf. 23] based on the transcriptions. The analysis was divided into two parts: one part, which focused the participants´ various contributions to the dialogue, and one part, which focused different subject theme in the dialogue. A color coding system was developed and used in both parts of the analysis to highlight the contribution of each individual as well as the corresponding themes. This color coding system made it possible to study how the various product representations (that were introduced during the meetings) affected the meetings and the information exchange and which roles the product representations played in facilitating the user-developer discussion.

5. Findings

The outcome of this study is presented from two perspectives; 'Creating the representations' and 'Using the representations'. The section 'Creating the representations' describes how the textile product representations for long-term EEG monitoring were created, while the section 'Using the representations' describes what occurred when these representations were introduced into the meetings between developers and users.

5.1 Creating the representations

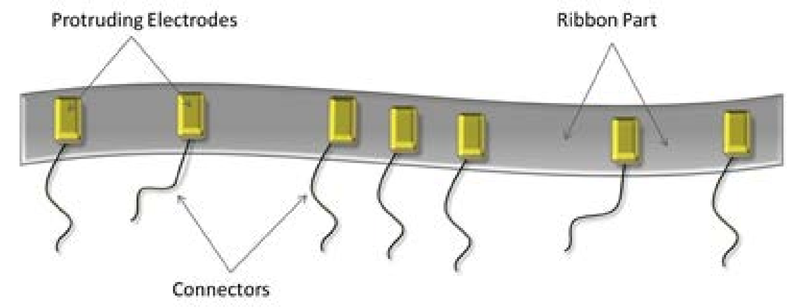
The completed prototype was preceded by a development process in which a series of textile product representations were created in an experimental and conceptual process. The product representations were initially constructed as individual components; this allowed the identification of the properties and functions of each representation respectively, prior to their being assembled to form the textile system.

Some requirements in the forthcoming product were identified from the users at the start of the project, for instance the conductive electrode surface, the smooth surface and the "easy to apply" aspect of the end product. However several requirements, such as a need of an isolation layer, prevention from evaporation, resilient property as well as contactable and attachable to the conductive part of the electrode, were "hidden" as neither the users nor the developer were aware about them when the project started.

One example of the individual components, which were designed to investigate the electrode surface properties, is the textile electrodes. The aim was to design a soft electrode surface with high signal conductivity; these constituted the two primary requirements for the electrode subsystem. Other properties such as stimulating local sweating and moisture-keeping properties to reduce the skin-to-electrode impedance were also investigated. A textile structure was designed and developed through multiple iterations. The design was tested by the users between each iteration and the developers received feedback regarding issues such as comfort, fit, adjustability, signal quality, etc., which formed a basis for the adjustments carried out prior to the users testing the next iteration.

The creation of the representations was mainly conducted using a cut-and-paste method, which informed and facilitated the construction and development of the textile system. This process further stressed the potential advantages of constructing the textile system using a novel three-dimensional weaving technique [cf. 24]. This weaving process allows a product with all the identified properties to be produced in one single process, avoiding the need to manufacture individual components separately and without need for any further bonding technique in order form the complete and final three dimensional structure. In addition, the weaving process facilitates the selection of individual properties for materials in the weft and the warp, as well as of individual weaving patterns for each layer in the structure.

Due to the flexibility of the weaving process, it is possible to select different types of yarn for different linear planes, and interlace them in order to form a unique structure according to user requirements,.



Schematic illustration of the ribbon with woven protruding textile electrodes.

Figure 1

The outcome of the project was a woven structure from which moisture-keeping, protruding, resilient electrodes were integrated in a woven ribbon (Figure 1). The technique allows each electrode to be positioned individually in the woven structure according to the international ten-twenty system for EEG signal acquisition [cf. 22].

5.2 Using the representations

The users participated in the process from the very beginning, offering their experiences regarding the limitations of the present solution and new product concept in actual use, something which the developers lacked. During the project, the users were given opportunities to handle the materials, discuss them, pose questions to the developers during project meetings, and test functions and properties in the intended use environments; the feedback then formed the basis for the next iteration of the representations.

Five different roles, which the product representations brought to the discussion, were identified, typically separately but sometimes one and the same representation adopted multiple roles:

- Demonstration, i.e. serve to demonstrate technical solutions;
- Verbalization, i.e. serve to fill in were words are missing or when terms are not understood;
- Visualization, i.e. facilitate team members to recall or adapt mental images of the

intended future product;
- Stimulation, i.e. inspire team members to generate new ideas or design;
- Integration, i.e. unite different perspectives within the development team.

The roles can be categorized into two main groups; as explanatory and concrete roles such as Demonstrate and Verbalize and as more proactive roles such as Visualize, Stimulate and Integrate. The roles appeared at different times during the development process and there was no clear time line associated with the different roles. Nevertheless, the explanatory and more concrete roles (i.e. demonstration, verbalization) were more frequent in the beginning of the project when the team needed to gain more knowledge about requirements and technical constraints as well as design possibilities, whereas the proactive roles (i.e. visualization, stimulation, integration) were more prominent when the project had proceeded for some time.

5.2.1 Explanatory and concrete roles

The 'Demonstrator' role occurred frequently when the developers introduced new design options or needed to demonstrate or clarify the influence that the proposed design might have on the forthcoming product. The product representation served as a demonstrator between the user and the developer and helped to concretize questions and answers. The questions and questioning are considered to have been a key element in achieving a higher level of shared knowledge. The physical existence and tangibility were important features of the product representation, i.e. when the users were able to physically handle and explore the product representations they were triggered to ask the developer questions about materials, functions, and design. In the same way the developer had the opportunity to ask questions concerning potential use and clarify whether or not the users' requirements had been met (or not). Furthermore the product representations provided the user with evidence regarding the feasibility of the technical solutions. This was obvious, for instance when one of the users exclaimed: “The prototype …I didn’t even feel it – no discomfort!” The representations exhibited the operation of the prototype (product) in use but they were also evidence of the developers’ acknowledgement of the users’ input to the design, something that most probably facilitated the user’s shift from passive observer to active evaluator.

When the product representation has the role of ‘Verbalizing’ it serves as a facilitator to fill in where words as missing or terms are not understood across the disciplines. Both the developers and the users used the representation to point at and asking questions such as “What is…?”. One example is for instance, when a user pointed at the product representation in front of him and asked: “Is that plastic?” Other ways of using the representation was to point at, and hereby localize, different elements, such as when the developer wanted to localize the exact position for one of the electrodes: “But this with the ear?... You start here?”

5.2.2. Proactive roles

The roles of ‘Visualize’, ‘Stimulate’ and ‘Integrate’ are of a more proactive character and occurred more frequently when the team had gained more shared knowledge and together could use the new knowledge to discuss the impact of different technical solutions.

'Visualize' denotes a situation when representations support individuals to recall or evoke mental images. When the representations support the creation of common visions or support mental images to be created and shared, they also support shared knowledge. This could be observed when one of the users gained awareness of another project's design which he wanted the team to take part of. The user created his own representation in the form of a hand-drawn sketch that visualized (his mental image of) the solution that he wanted to share with the team: "… I saw something... ". The hand-drawn representation visualized not only the user's contribution in terms of a design solution but also enabled the developer to share her mental image of the future solution: "... It is similar to what I am thinking of ...". By using the product representations to visualize different mental images a more unified view of the design was developed between users and developers which supported the process of sharing knowledge.

Product representations can also assume the role of 'Stimulator' and is identified when the product representations encourage a process whereby an individual becomes inspired or enthusiastic. This facilitates the generation of new ideas or design solutions and, hence, the progression of the project. As an example, the product representation enabled the users to gain deeper knowledge of the technical solution and the representations stimulated the users to see more opportunities in how the future product can facilitate their daily work: "…This is interesting …" By means of the physical and tangible product representations the user gained more thorough understanding of the technical solutions and its potential and the representations enabled the user to see future possibilities. "... there is much to gain ... it can be improved so much ...".

The fifth role, 'Integrator', is the most complex one and can be defined as a representation bringing parts together, unifying or incorporating (parts) into a whole. The representations facilitated the integration of perspectives between the different disciplines and supported to unite different perspectives in the team. One example is when the developer demonstrated and visualized, with various physical representations, how the technology could enable the design of the textile system and one of the users began to understand and grasp, on a more detailed level, how the developers intended the design of the product "… So it is not entirely science fiction to imagine that you can weave everything in one piece … with conductor and surfaces and everything....." This led the other user (with a signal engineering background) to integrate the information with his own expertise "… O yes…. several layers... the circuit boards are made like this… with various conductive layers".

Thus, using product representations, users' and developers' views can be integrated. Knowledge can be understood and converted into an individual's own area of expertise which can contribute to evolve shared knowledge, support the integration of knowledge and understanding of different actors' contributions to the development process of the future product.

6. Conclusion and discussion

New technologies provide us with new materials and possibilities to integrate functions in textiles in ways which have not been possible before. This may, to some degree, replace contemporary production methods as the development of new, "smart textiles" is pushing the textile sector towards a paradigm shift where new processes, new ways of working and new roles need to be developed. This implies challenges for the future of the textile industry, which today often can be unaccustomed to “taking the lead” for the development process of new innovative products, as well as it might be unfamiliar with developing products in multidisciplinary contexts. The textile industry needs to shift perspective from being a supplier, where other stakeholders initiate the innovation, to be an actor that initiates multidisciplinary teams to develop tomorrow’s multifunctional textile products.

Users’ knowledge and experience of use can be argued to form a particular discipline. The importance of getting users involved early in the development of new innovative products is argued since the users are the ones who have the best knowledge and experience of the product in use, and can discover needs in the forthcoming product that have to be fulfilled as the process evolves. Involving users adds however further complexity to the multidisciplinary team.

The main result from the study is that the product representations can support in different ways the team’s exchange of knowledge and experience so that the team can generate new and shared knowledge. The product representations may also support the process in which the users can move from being passive evaluators to becoming co-developers.

The product representations may have different mediating roles; to *demonstrate* which can help to demonstrate and explain for the users what 3D textiles can be for instance and demonstrate properties such as hardness, pressure distribution, surface characteristics and shape. Additionally it may also support the developer when new materials are introduced and technical properties needs to be explained and understood for the users.

Textiles can act as *verbalizer* and support the dialogue between the user and the developer when words are missing or words are not understood cross disciplines borders. The textile verbalizer can support explanations since it can be used to point at, stretched or bended but it can also support to be understood when words are misunderstood or misinterpret. For instance, a word such as 'smooth' (which was one requirement from the users in this case) is an individual evaluation of a property, with little possibilities to be described in technical terms. However, through a haptic feeling by tactile touch of a textile material the experience of smooth or rough surface can be obtained and may support a common objective of such property.

The textile material supports both the developer and the user to externalize mental images by *visualizing* a textile material, its structure, properties or function. Different textile materials can easily be combined to create new shapes and new structures which may support the dialogue when the next step in the development is discussed. Textile material can visualize the use of something, the shape of something as well as the physical properties of a part of the forthcoming product. Thus textile properties such as drapability, folding, used completely flat or in combination with other materials (textile or not) the users and the developer can lend the textiles´ properties to support the ideation of new solutions.

A *stimulator* can stimulate the team members to encourage and inspire individuals to generate new ideas or solutions. A fabric's tactile properties can encourage users and developers to use senses other than sight and hearing, for example, and make use of the fabrics tactile properties. To feel the textile´s properties (flexibility, strength, elasticity, ability to bend etc.) may stimulate an individual to create new ideas or new solutions to a problem.

The most difficult but also the most important mechanism to achieve is to integrate different perspectives and thus develop a common objective in multidisciplinary collaborative situations. The role of *integrator* may functioning single or together with all of the above for mentioned roles, to create an equal understanding, create a community of or shared understanding.

By use of textile prototypes and materials textile can lend its properties, such as tangibility, drapability, folding properties, ability to be pressed, feel of haptic surface, to elicit various scenarios of functions or properties. The textile prototype can thus facilitate to integrate different perspectives and different knowledge. All the roles regarding the functions and features of the forthcoming product can support the development process with knowledge and ideas that may not be possible to achieve without them.

By increasing the awareness on how product representations may facilitate the dialogue between users and developers, the textile industry may take the step from traditional textile development to a more user-oriented approach where product representations can support real user involvement.

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